

# SCIENCE SKETCHES

## CHEMISTRY ITS EVOLUTION AND ACHIEVEMENTS

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F. G. WIECHMANN



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ITS

EVOLUTION AND ACHIEVEMENTS

BY

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WITH LOVE  
TO  
MY WIFE



## PREFACE.

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It seems to the writer that space might be found on the bookshelves of lovers of knowledge for some modest volumes, which, without wish or pretence to displace any learned treatises on the topics they discuss, would offer to their readers a correct and concise synopsis of the subjects they consider.

Works of this description,—Science Sketches would seem an appropriate designation for them,—should prove welcome to all who take a general interest in science. They should be of value to students entering upon some special field of study, presenting them with a general survey of their chosen ground, and perchance might be acceptable even to workers in various branches of science, affording them a ready acquaintance with the trend of thought in domains of learning other than their own.

Some knowledge of the various phases through which a science has passed is,

moreover, of value in teaching one to place a more just—perhaps it were better to say, a more modest—estimate on the theories of the day. For, while it is indisputable that a truth once discovered is never lost, although the form in which it is embodied may be altered, yet it is also beyond question that doctrines and dicta pass away, even as the men who formulate and pronounce them.

The aim to enlist the interest of non-professional readers in an exact science, is an undertaking not without its difficulties. On the one hand, care must be taken not to ground on the shoals of superficiality; on the other, heed must be had not to drift into currents which would speedily carry beyond touch of all soundings. The selection of a course that shall pass clear of either danger certainly calls for the exercise of careful consideration.

Preparation of this sketch, "Chemistry: its Evolution and Achievements," has been attempted on the lines indicated. It is submitted to its readers in the hope that the grandeur and the charm of the science may prove discernible even through the veil of an inadequate presentation.

The writer's indebtedness to the authors he has consulted, is indicated by a list of their works which is appended; acknowledgment is furthermore gratefully made of his special obligations to the classic writings of Hermann Kopp, the great historian of chemistry. Many of the chronological data, appearing in the index of names, were secured from various journals, biographies, dictionaries and encyclopædias.

F. G. W.

*Manhattan.*

*1899.*





CHEMISTRY:  
ITS  
EVOLUTION AND ACHIEVEMENTS.

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La pensée et la matière—thought and matter, was the explanation of Rodin, the sculptor, when asked about the significance of one of his beautiful creations,—a woman's head, broad of brow and of thoughtful mien, emerging from, yet fettered by, the rock which gave it life.

No representation more fitting than this could be selected should one seek to symbolize the Birth of Chemistry.

Chemistry, the science of matter, has taken origin in, and rests upon, a basis of fact broad, massive, secure.

Even as aeons have measured the slow accretion of the rock which has so admirably served the sculptor's purpose, thus passing ages have witnessed the gradual accumulation and slow growth of the material from which there has been wrought the science of chemistry we know to-day.

Its beginnings are lost in the haze of the remote past and undoubtedly date back thousands of years to the time when the pressing needs of man taught him to adapt to his own ends the means and the materials which Nature placed at his disposal.

Passing beyond the domain of history and entering the realm of legend and tradition, we learn that the first to receive instruction in chemical lore was—woman.

Thus, in the book *Henoch*, originally written about 1115-1110 B.C., account is given of intimate relations existing between certain angels and some denizens of this world.

One of these angels, Azâzêl, is said to have taught women some of his arts, the making “of jewelry and the use of rouge, and the beautifying of the eyebrows, and the most valuable and choice stones, and all coloring-matters, and the metals of the earth.”

This legend is also met with in the *Homilies*, formerly ascribed to Clemens Romanus, and it recurs in the following, the third, century, in the writings of Tertullianus, *De cultu feminarum*. Zosimos, who probably lived in the fourth

century, likewise quotes this story. It would thus appear that even in those days chemistry was held to have been imparted to mankind in a distant past.

In some of the earlier writings of the alchemists these legends re-echo, for they also express the belief that chemistry, in the sense then attached to the word, had first been confided to woman by superior beings. In a script claimed to have been addressed by Isis to her son Horos, Isis relates that she had imposed on the angel Amnaël, as the price of her favor, the condition that he teach her the secret of making gold and silver; she furthermore states that she had succeeded in obtaining the fulfillment of her desire.

But recently news has come from the far East that Monsieur E. Amélineau has discovered, at Abydos, in Egypt, the tombs of the god-kings Osiris, Seth and Horos. This discovery would seem to remove from the realm of myth-land, Osiris, Isis (his sister-wife, for her name is mentioned on the tomb), and Horos, their son; it seems to place before us tangible evidence of the existence of mortals, who lived ten thousand years ago.

May we hope that this tomb, whose silence of ages has at last been broken,

will yield some clue to the fabled, priceless secret of Isis? For, have we not the testimony of Zosimos to the effect that precepts for the making of gold were hewn in stone in the temple of the Egyptian god Pthah?

A legend to be found in the chronicles of John of Antioch (about the seventh century) would interpret the story of the golden fleece as a record of the art of making gold by chemical means; these directions were said to have been inscribed upon the skin of an animal.

There seems to be no positive evidence to the effect that the Greeks and Romans were acquainted with the idea of the transmutation of metals,—that is to say, with a belief in the production of precious, from base metals. A passage in the works of Pliny, *Historia naturalis*, has, however, often been interpreted to this effect. Even the works of Homer have by some been thought to hold alchemistic teachings and wisdom.

The oldest manuscript on chemistry, known at the present time, is a papyrus preserved at the University of Leyden. This papyrus is a book consisting of twenty leaves. Eight of these—that is to say, sixteen pages—are covered with

beautiful and most legible writing in unical characters.

This papyrus came from Thebes, in Upper Egypt, and is believed to have been made in the fourth century of our era, if not at an earlier period. It consists of a collection of one hundred and one precepts, many of these bearing on the chemistry of the metals. It appears to be an abstract made of other works, for it frequently gives several methods for the accomplishment of a given purpose. A Latin translation of this document, by Leemans, appeared in 1885; a French version of the same was published by Berthelot.

As to the origin and meaning of the term chemistry, *chimia*, in the form of *scientiam chimiae*, occurs for the first time in the writings of Julius Maternus Firmicus, who lived in the first half of the fourth century. It is, however, open to question whether the word was by him used in the sense and as having the meaning which attached to it later. In some of the earlier editions of the astrology of Firmicus, entitled *Mathesis*, notably in the one printed in 1497, the expression is given, not as *chimiae*, but with the Arabic prefix, as *alchimiae*.

Origin  
of the  
word  
Chem-  
istry

Zosimos uses the word *chema* for the knowledge imparted to man by superior beings, and employs the term *chemia* apparently for designating the art of producing metals.

The earliest Greek manuscripts which deal with these subjects rarely use the expression *chemia*, but, instead, refer to the art of coloring, the art of making gold, the art of philosophy, and the sacred or divine art.

The origin of this term has given rise to much study and comment. It has been held to have been derived from the Egyptian, the Arabic and the Greek, and various roots in these several languages have been assigned the role of its sponsor.

Plutarch, in the second half of the first century, states in his work, *Isis and Osiris*, that the priests of Egypt designated that country as *Chemia*, because of its black soil. The black part of the eye, the pupil, was also known by this same term.

It has been suggested that the word has been derived from the Arabic word *kema*, which means hiding, secreting, and that the word *al-kîmijâ*, Arabic for chemistry, therefore originally signified the knowledge of the hidden, or the secret

art. The Arabians, however, primarily designated by this word a preparation made from the philosopher's stone, which could bring about a transmutation of other metals into gold or silver.

Other writers have maintained that the term was coined from the name of an Egyptian king, *Chemmis*. In Sanscrit, *kéma* means gold, and the possibility of a derivation of the word *chemia* from this root has not been left unnoticed.

The word has also been written as *chymia* and as *chimia*, and attempts have been made to trace its derivation to the Greek *chymos*, fluid or sap; it being inferred that the term was intended to indicate the art of working with solutions.

Before the fourth century of the present era, chemistry, in the sense of a science, did not exist. Up to that time no attempts had been made to collate known facts, or to pursue the study of natural phenomena for the attainment of any one definite aim or purpose.

The oldest races of man of whom records have been preserved, were in possession of more or less knowledge of a chemical nature, all of which, however, had been empirically acquired.

Early  
Chem-  
ical  
Knowl-  
edge



Knowledge of metallurgical processes dates back to the very earliest of times. The originating of these arts and operations was, by most nations, ascribed to their gods or heroes, and, in nearly all instances, a certain acquaintance with the working of metals will be found to be coeval with the beginnings of a nation's history.

The Egyptians, Phoenicians, Greeks and Romans were among the nations possessing empirical knowledge of certain chemical facts and processes. With the Egyptians the natural sciences were taught in the temples, by their priests. This knowledge was carefully guarded and the cult was shrouded in mystery. It is not impossible that the Egyptians had some conception of chemistry as a science, but the evidence to this effect is by no means conclusive.

In the days of Homer, about 1000 B.C., the Greeks regarded iron as a most precious metal ; this would indicate that at that time the Greeks could not have been possessed of a very extensive metallurgical knowledge.

Pliny is authority for the story, that once Tiberius was offered a cup wrought of a beautiful metal ; this metal was

lighter than silver, but closely resembled the same in appearance. Learning that the metal of which the cup was made had been obtained from clay, and that no one save its maker knew the process of its extracting, Tiberius had the unfortunate man destroyed, so that his secret should perish with him and that a depreciation of the precious metals, which might have been caused by this newly found material, might be avoided. More than eighteen centuries passed by ere the soft lustre of aluminium was again beheld by the eyes of man.

The art of dyeing was known to the Egyptians, the Phoenicians, the Greeks and the Romans. In the manufacture of pottery the Egyptians excelled; they sometimes glazed their bricks and used colored enamel in the decorating of finer pieces of pottery. The making of glass was probably also an invention of the Egyptians, notwithstanding that popular belief ascribes the discovery of this art to the Phoenicians. The sons of "the black soil" furthermore possessed a knowledge of embalming, being familiar with the use of certain chemicals which arrested the decay of organic tissue.

The preparation of various beverages

by fermentation was also known in those early times,—the mead of which old Norseland sagas have so much to tell, was thus made from honey.

**Early  
Systems  
of  
Natural  
Philosophy** The ancients did not possess much knowledge of Nature which was based upon observation and experimental investigation. As a rule, their natural philosophy was purely speculative, although there were some thinkers in those times who were as keen in observing as in reasoning.

Most of these philosophers, however, took some assumption to be true and then endeavored to reason out conclusions from their premises. That their conclusions were often not only at variance with the truth, but diametrically opposed to it, may be easily imagined. While the fact is well known that speculations concerning the ultimate particles of the primary constituents of the universe were indulged in in very early times, it must be clearly understood that such speculations of the early philosophers were entirely distinct from, and independent of, any knowledge of chemical facts possessed at the time.

Having given a passing glance at some of the chemical data in possession of

the ancients, it may be of interest to consider briefly the views entertained by them in respect to the nature and the constitution of matter.

The oldest teachings of India held that the world was made of wind, water, earth, fire and ether. Air, water, earth and fire, the four so-called "elements," were by Empedocles of Agrigent regarded as the basis of the world. About the fifth century before our era, Democritus of Abdera assumed the existence of a primal form of matter. This he imagined to be made up of the smallest possible particles, which differed from one another in form and size, but not in the nature of their substance. These particles were supposed to be in a state of continuous motion, forever entering into combinations, which combinations anon suffered disintegration.

Aristotle, a pupil of Plato and the preceptor of Alexander, son of Philip of Macedon, was the author of a system of philosophy which has endured longer than any other system of philosophy the world has ever known. Even in the middle ages his views held dominance and were regarded as the embodiment of all knowledge and truth. He considered

Philosophy of  
Aristotle

the properties of bodies to be the result of the simultaneous occurrence and intermingling of certain fundamental conditions ; his teachings regarded component elements only in the sense of bearers of these fundamental properties. Aristotle was far from looking upon the elements as ultimate particles the existence of which could be demonstrated and through the combination of which all bodies of the universe were formed.

The primary qualities, in his opinion, were those which were perceptible to the sense of touch—for instance, warm, cold, dry, moist, heavy, light, hard, etc. Of these, he recognized the first four as the fundamental properties, partly because the other properties were not so common, and partly because they could be regarded as secondary phenomena caused by combinations of some of the former. He assumed that each element was endowed with two fundamental qualities, and as one and the same element could not, at the same time, have two antagonistic properties,—could not, for instance, be both wet and dry,—only four combinations were possible. The four elementary conditions of matter he distinguished were : fire (simultaneous

dryness and heat), air (heat and dampness), water (cold and dampness), and earth (cold and dryness). In addition to these, this sage assumed the existence of a fifth element. This was rather of a more ethereal nature, and was termed "Æssentia." The Arabians accepted the doctrines of Aristotle about the sixth century, and up to the sixteenth century the teachings of his school claimed as devoted believers and adherents most scholars of all nations.

The simpler substances into which complex substances could be resolved were, by the scholastics, termed elements. Non-decomposibility and the possibility of suffering transmutation were regarded as properties common to all elements. The latter quality was held to be dependant on the similarity of the fundamental properties of the elements believed to be transmutable. As Aristotle taught, each element was possessed of two properties, one in a greater, the other in a less degree. Owing to the preponderance of some one property which two elements had in common, one element could readily be transformed into the other. Thus, air was warm and damp, water was damp and cold ; hence,

**Teach-  
ings  
of the  
Schol-  
astics**



air could be transformed into water, and water into air.

Density was considered as the result of cold, which caused the particles of a body to approach close to each other. Porosity was regarded as the effect of warmth; hardness as the result of dryness; softness was believed to be produced by dampness, and so forth.

Again, the elements were classified as light and heavy. The former were fire and air; of these, fire was the absolutely, air the relatively, light element. Water and earth were the heavy elements; water the relatively, and earth the absolutely, heavy element.

**Belief  
in the  
Trans-  
mutation  
of  
Matter** Given such views and doctrines, it is not difficult to understand that the most marvelous tales of transformations and transmutations could gain general credence. Water, from the earliest times, was looked upon as a simple, undecomposable form of matter. The Egyptians and the inhabitants of India regarded it as the fundamental substance from which many, if not all, other substances had been produced.

Thales, in Greece, about 600 B.C., thus taught, and Aristotle, as has been previously mentioned, considered water one

of the elements. Pliny ascribed the creation of water, the forming of clouds, to the condensation of air ; air—that is to say, wind—was believed to be produced from water.

Crystalline quartz was supposed to consist of water. Diodor, about 30 B.C., held that it was formed from the purest of water by the action of divine fire. The Greeks called quartz *krystallos*, which signifies ice, and thus indicated their belief that quartz was formed from water—not, however, through the agency of fire, but through long-continued cold. Pliny, Seneca and others also bear testimony to this effect.

Agricola, in the sixteenth century, was probably the first to dispute this assertion ; he suggested that if crystalline quartz be made from water, in the manner suggested—that is, as ice is formed—then it too, like ice, should be lighter than water, and should be capable, like ice, of floating upon water. These views of Agricola found some supporters, still, belief in the possibility of the transmutation of water into stone or into earth was seriously discussed in Europe, even by eminent experimentators, but little more than one hundred years ago.



**Alchemy** The origin of alchemy is undoubtedly to be sought for in remote antiquity. The legendary lore of the subject—tales of fair temptresses and of fallen angels, the story of the golden fleece and other traditions—have been previously recounted.

Most alchemists agreed upon Egypt as having been the home of their art, and acknowledged Hermes Trismegistos as one of the earliest masters, if not as the originator of their creed and craft. It seems impossible to determine the individuality of Hermes—if, indeed, he does not prove to have been but a purely mythical creation. However that may be, his name occurs frequently in alchemistic treatises which were written later than the fourth century.

In the eleventh century, an alchemist, Hortulanus, made public a Latin version of a brief essay which he ascribed to Hermes, and which came to be known as the *tabula smaragdina*. It is not known in what language this precept was originally composed, but it is probably one of the earliest of alchemistic writings. The Latin version of Hortulanus, as given by Kopp in his *Geschichte der Chemie*, is here reproduced and is followed by an

English translation, for which the writer is indebted to a kind and learned friend.

### TABULA SMARAGDINA.

Verum est sine mendacio, certum et verissimum: Quod est inferius est sicut id quod est superius. Et quod est superius est sicut id quod est inferius, ad perpetranda miracula rei unius.

Et sicut res omnes fuerunt ab uno, meditatione unius: sic omnes res natae fuerunt ab hac una re, adoptione.

Pater ejus est Sol, mater ejus est Luna. Portavit illud ventus in ventre suo. Nutrix ejus terra est. Pater omnis telesmi totius mundi est hic. Virtus ejus integra est, si versa fuerit in terram.

Separabis terram ab igne, subtile a spisso, suaviter, magno cum ingenio. Ascendit a terra in coelum, iterumque descendit in terram, et recipit vim superiorum et inferiorum.

Sic habebis gloriam totius mundi. Ideo fugiet a te omnis obscuritas.

Haec est totius fortitudinis fortitudo fortis, quia vincet omnem rem subtilem, omnemque solidam penetrabit.

Sic mundus creatus est.

Hinc erunt adaptationes mirabiles, quarum modus est hic.

Itaque vocatus sum Hermes Trismegistus, habens tres partes Philosophiae totius mundi.

Completum est, quod dixi de operatione solis.

### THE EMERALD TABLE.

True it is without a lie, sure and most true;

what is below is like that which is above. And what is above is like that which is below, of one substance to perform miracles.

And as all things have come from one being, the meditation of one, so all things have been generated from this one thing by adoption.

Its father is the sun, its mother is the moon. The wind has carried it in its womb. Its nurse is the earth. The father of every talisman of the whole world is this. Its power is unimpaired when it is turned upon the earth.

Separate the earth from the fire, the subtile from the material, gently, with great cleverness. It rises from earth to heaven and again descends upon earth, and receives the force of those above and those below.

Thus thou wilt have the glory of the whole world. All obscurity, therefore, will leave thee.

This is of all strength the strong strength, because it will subdue every subtile thing and penetrate every solid.

Thus has the world been created. Hence there will be wonderful adoptions whose measure is this.

Therefore I have been called Hermes Trismegistus, possessing three parts of the philosophy of the whole world.

What I have said of the operation of the sun has been fulfilled.

And the meaning of this word-jungle through which reason vainly seeks to blaze a trail? Ah,—“that is another story.”

The earliest piece of historical evidence which can be adduced in support of the claim that attempts were made to obtain gold and silver from alien substances, dates back to the fourth century. Themistos Euphrades, a Grecian orator of the time, refers to the transmutation of copper into silver and of silver into gold as well known facts. But the first indisputable record of belief in the transmutation of silver, tin and copper into gold, occurs toward the end of the fifth century, in the writings of Aeneas Gazaeos, a native of Syria.

As Kopp has well pointed out, it is not unlikely that in those early times a covering or plating of gold or silver may have been regarded as an actual transmutation of the gilded or silvered objects into the precious metal.

It was probably the production of alloys having the color of gold or of silver, that first led to a belief in the possibility of transmutation. An alloy of copper with an impure oxide of zinc exhibits a yellow color ; copper with arsenic yields a silvery white compound ; mercury and lead form an amalgam which could easily be, and was, mistaken for tin.

Obtaining silver from a lead ore, in

which it occurred naturally, was, by the alchemists, regarded as proof that a precious metal could be produced from a base metal by transmutation. The deposition of metallic copper on iron, when this was inserted in a solution of some copper salt, was considered a case of conversion of iron into copper. Distillation of a gold or silver amalgam which resulted in the securing of the precious metal and the loss, by volatilization, of the mercury was, by the earlier alchemists, taken as a proof of the creation of the metal which remained in their hands after completion of the process.

Alchemy, therefore, most likely had its origin in a misconception and misunderstanding of phenomena imperfectly observed.

**Spread of Alchemy** Egypt was certainly the home of alchemistic learning during the first centuries of the present chronology. Alexandria with its high-school, destroyed in 642, formed the central station where adepts prosecuted and taught their mysterious cult.

A new era for alchemy began with the conquest of Egypt by the Arabians in the year 640. The conquerors soon came to realize that a mere simulation of color

in alloys did not make gold and silver of those alloys. They, however, firmly believed that a complete transmutation of one metal into another could be effected, and the achievement of this end formed the goal of their ambition and endeavor.

Knowledge of alchemy—the Greek term *chemia* to which the Arabic article was prefixed—was carried by the Arabians to Spain, which country they entered in or about 711, after having passed through northern Africa. From Spain alchemy spread over western Europe; in the thirteenth century the Hermetic art, or the art of the sun, as alchemy was also termed, had its adherents, the so-called adepts, in Germany, France and England. The two following centuries witnessed extension of the art in other parts of the world, but also initiated its decadence in Spain.

The original and principal aim of alchemy was the production of a substance which was variously designated as the philosopher's stone, the great elixir, the great magisterium, and the red tincture.

**Aims of  
Alchemy**

This material was supposed to have the power of transmuting base metals into gold,—in fact, of creating gold, for a



small quantity of the philosopher's stone was believed to suffice to produce large quantities of the precious metal.

There seems to have been a considerable difference of opinion among the adepts as to the extent and the powers of this medium. Some held that it could transform every base metal and any amount of it into gold ; others, that in a less perfect condition it could transform only a limited amount of some certain base metal.

Some of the earlier alchemists distinguished between a great and a small elixir, or a red and a white tincture. The former of these was deemed capable of accomplishing the transmutation of base metals into gold, the latter of effecting their transformation into silver only.

**Manu-  
facture  
of the  
Philoso-  
pher's  
Stone**      Directions for making the philosopher's stone are numerous and varied, and often mutually contradictory.

To outline the process in a general way, it appears that, naturally, the first requisite was the securing of the crude material to be used. This substance was known as *materia prima cruda*, as *terra virginea*, and by various other terms, and the obtaining of this substance was regarded as the most difficult part of the



whole undertaking. “Il n’y a que le premier pas qui coûte,”—as the French have it. Although it was believed to occur in great quantities, its identity was unknown to the workers and the search for this substance extended to and through almost all things under the heavens.

From this *materia prima cruda* there was to be obtained the *materia prima matura*, also designated as *mercurius philosophorum*, *chaos*, *azoth*, etc.... a substance in which the principles of mercury and of sulphur were believed to be contained in the state of greatest purity.

To this *mercurius philosophorum* there was then to be added *auro philosophorum*, philosopher’s gold, and this mixture, carefully guarded from the air, was digested at a low heat for a considerable length of time. This operation was carried on in the *ovum philosophicum*, a vessel of a form carefully prescribed. As a result of this proceeding, which the alchemists termed cineration, corruption, or the death of matter, a black body was obtained—the *caput corvi*, or raven’s head.

Through continued digestion, termed albification, purification, resurrection, this black substance became transformed

into a white body — the swan. When this latter had been secured, the temperature to which it was exposed was raised; the substance turned yellow and finally a brilliant red. And then—Behold! the philosopher's stone in its greatest perfection!

**Descriptions of  
the Philosopher's  
Stone**

The descriptions of the appearance of the great magisterium differ widely, as given by various alchemists. By some it was spoken of as a red powder, by others it was said to possess a peach-blow color; others still affirmed it to be of grey appearance. Paracelsus, in the sixteenth century, described it as a very stable substance, red as a ruby and transparent as crystal, pliable as gum, and yet fragile as glass. In the powdered state, it was said to resemble saffron.

As to the amount of the substance which was to be used in order to transmute a given quantity of base metal into gold, the statements also differ materially. The more perfect the philosopher's stone, the less of it, it seems, was required. Roger Bacon stated, that one part of this substance could transmute one million parts of base metal. From this statement down the estimates vary, until one adept, Kunkel, in the latter

part of the seventeenth century, modestly claims that one part of the philosopher's stone can transmute but two parts of base metal.

Belief in the possibility of transmutation was, as previously indicated, originally based upon the view held with regard to the constitutions of the metals. All metals were believed to be compounds, and were regarded as being composed of two substances which varied in amount and in degree of purity; these factors determined the nature of the metal. The names assigned to these two substances were mercury and sulphur, but these terms were used, not to denote the elements which are now so called, but they must rather be regarded as standing for the conceptions of certain properties. Under the term *mercurius*, the alchemists seem to have understood the idea of the non-decomposable; they saw in this constituent the cause of metallic glance and of malleability. The term *sulphur* was used by them to express the idea of transmutability and of combustibility. Different metals were regarded as compounds of these two substances in different proportions. Gold, for instance, was regarded as a compound of much mer-

cury with but little sulphur, but both in the state of greatest purity and in firm combination.

Basing then on the conception that other metals differed from gold solely in the proportions in which these constituents, mercury and sulphur, were present, it seemed not unreasonable to seek for an agent whereby these proportions could be readjusted and gold produced.

**Powers  
of the  
Philoso-  
pher's  
Stone**

In the course of time other wonderful properties, besides the power of effecting the transmutation of metals, came to be ascribed to the philosopher's stone. For instance, it was reputed to have the power of curing all ills that flesh is heir to.

Thus, *Faust*, in Bayard Taylor's masterly translation of Goethe's classic:

“ My father's was a sombre, brooding brain,  
Which through the holy spheres of Nature  
groped and wandered, .

And honestly, in his own fashion, pondered  
With labour whimsical, and pain:

Who, in his dusky workshop bending,  
With proved adepts in company,  
Made, from his recipes unending,  
Opposing substances agree.

There was a Lion red, a woer daring,  
Within the Lily's tepid bath espoused,  
And both, tormented then by flame unsparing,  
By turns in either bridal chamber housed,  
If then appeared, with colours splendid,  
The young Queen in her crystal shell,  
This was the medicine ” . . .

This medicine was styled "the great panacea," and it was claimed by some of the adepts that its possession would confer eternal youth and life on its favored owner.

This belief in its powers, however, does not occur before the eighth century and probably crept into existence gradually owing to Europeans attaching too literal a meaning to some of the earlier descriptions of its properties, given, at times, by the Arabians, with all the splendor of Oriental imagery. . Thus, Geber termed the base metals invalids which he would cure, that is, transmute, by aid of the philosopher's stone ; others wrote of curing through its help the dread evil—poverty. A misconception of the kind indicated could thus have arisen very easily, and having once been formed, would naturally but serve to stimulate the zeal of the adepts in pursuit of their life's quest.

Another object which some alchemists sought to attain was the making of lamps that would burn forever ; gold in the liquid state was reported to be the principal ingredient of the fluid which was to furnish the perpetual light. Belief in the existence of such lamps

was prevalent in the sixteenth and in the seventeenth centuries, and quaint and curious are the legends which tell of such wondrous lamps having been found burning in tombs and sepulchres, but which were instantly extinguished on coming into contact with air.

About the year 1600, a German physician, one of the most eminent alchemists of his time, claimed that the philosopher's stone could transform quartz into gems, could change a thousand pearls into one pearl of exquisite beauty and could render glass malleable. Even the imparting of moral culture, redemption from sin and evil, was believed to lie within the power of this magic substance. Sendivogius, about the commencement of the seventeenth century, considered the philosopher's stone to be a mirror and claimed that he who possessed it could, on peering into the same, behold therein three parts of the wisdom of the whole world and thus would grow to be as wise as Aristotle and Avicenna.

But it would be idle and lead too far to attempt here a recounting of the many marvelous tales of miracles of various kinds said to have been accomplished by the aid of this agent of agents.



The story—and *Finis* has not even now, at the end of the 19th century, been written beneath the final chapter,—is one of intense human interest. On the one hand, one finds most unselfish devotion and self-sacrifice in the pursuit of an impossible ideal; on the other, a sinking to the lowest depths of deception, fraud and infamy.

Turning the broad and well-worn pages of some ponderous old tome on this occult art,—written perchance centuries ago and heavy with the dust of ages,—one seems transported into a realm of magic and necromancy. Mysterious symbols alternate with equally mysterious and unintelligible directions for the guidance of the seeker after knowledge. We of to-day who examine these writings in the clear, calm light which Science sheds on their pages, may wonder at the power which has been theirs to hold even master-minds in bondage,—a Newton and a Leibnitz were not above their magic spell,—but still we cannot repress a feeling of compassion and of regret for those unnumbered thousands, whose hopes were foreordained to disappointment, whose struggles were foredoomed to failure, but who, notwith-



standing, pursued to the bitter end the luring glitter of the phantom gold.

**Iatro-  
Chem-  
istry**

The sixteenth century witnessed the differentiation of chemistry from alchemy. While alchemy of course continued to claim numerous adepts, other interests began to attract the attention of many students of natural science.

The belief that chemistry should serve the interests of medicine, became the guiding star of our science during the next epoch of its development. But here and there work of a chemical nature was done also in other directions. One personage who comes rather prominently into view at this time is Georg Agricola, a German, who may be said to occupy a position of his own in a time the chief trend of which was towards the healing art.

Agricola, although a physician, can perhaps best be described as an industrial chemist. He gave his attention largely to the study of metallurgy and industrial pursuits and in 1546 embodied his knowledge of metallurgical processes in a work entitled : *Libri XII de re metallica*.

It was Paracelsus, or, to give him the full benefit of his name, Phillippus Aureolus Theophrastus Paracelsus Bom-

bastus von Hohenheim, who asserted that medicine was but chemistry applied, and it was mainly through his labors and his influence that chemistry and medicine came to be regarded as so closely allied. Under his guidance and that of his followers, the guardianship of chemistry passed more and more into the hands of physicians. The new departure thus initiated by Paracelsus and his disciples, of whom Van Helmont and Franz de le Boë Sylvius were the most distinguished, is generally known as the period of iatrochemistry.

During this epoch it was commonly believed that health as well as sickness was dependent on chemical processes. Normal physiological phenomena, the conditions of life in its usual state, were regarded as chemical functions in which the active constituents reacted on one another in proper proportion. Pathological phenomena were held to depend upon a disturbance of these normal processes; one or another of the constituents predominated unduly; in short, disease was regarded as an abnormal chemical process and therapeutics was charged with the task of neutralizing, by chem-

ical means, such constituents as might be present in excess.

It is Van Helmont who should be credited with being the first to suggest the rudiments of chemical physiology. He searched for the actual substances in organic matter, and compared the reaction of various juices which mingle with one another in the organs, to the action of such juices outside of the organs. His views on the constitution of matter were of great importance to chemistry, for he was the first to formally denounce the theory of Aristotle, and to demonstrate that fire is no element.

He also declined to accept the theory of Paracelsus, that all metals consisted of mercury, sulphur and salt,—terms, of course, used in a sense different from that which now attaches to the same. Van Helmont was also the first to announce, that in the formation of chemical compounds, the original substances remain, although they may undergo chemical changes. This claim probably heralds the first dawn of that important and brilliant conception—the indestructibility of matter.

Van Helmont regarded water as the

primal principle of all matter. That it was present in organic substances, he inferred from invariably finding it as a product of combustion of organic bodies. He believed in the transformation of water into earthy matter, and in proof of his assertion adduced the fact, that a tree which he had planted in a weighed amount of soil and which was watered carefully for five years with rain and distilled water, had experienced a gain of one hundred and sixty-four pounds, while the soil in which it had been grown had lost but a couple of ounces in weight. Van Helmont also gave considerable attention to the study of gases, and described carbonic acid gas, a product of fermentation; he named it *gaz-sylvestre*.

In his eyes, the noblest aim to which chemistry could aspire was the discovery of a universal solvent, for it was held that substances could not experience chemical changes unless they were in a state of solution. This same ideal substance should also act as a universal medicine; it was designated as the *menstruum universale*, or the *alkahest*. Its preparation was depicted as the crowning glory of chemical achievement.

Andreas Libavius, although a believer in the main tenets of alchemy, contributed much to the progress of chemistry by his valuable discoveries and observations. He pointed out many of the follies and errors of Paracelsus and his school and was the first to collect in his writings all of the principal chemical facts which were then known. His treatise, *Alchymia*, published in 1595, is regarded as the first text- and hand-book of chemistry.

Among other men prominent in chemical science in those times there should be named Daniel Sennert and Johann Rudolph Glauber. Both were Germans. The latter has been regarded as one of the best chemists of his day. Otto Tachenius, a countryman of Sennert and of Glauber, and a devoted pupil and follower of de le Boë Sylvius, made some valuable contributions to the knowledge of the composition of chemical substances. He originated the definition of the term salt: a compound of an acid and an alkali. He also studied the proportions by weight in which substances react chemically, and noted the increase in weight which takes place when lead is transformed into its oxide.

During this period of iatro-chemistry the interests of chemistry were served to good purpose, chiefly because its care was removed from the exclusive control of the alchemists and entrusted in great part to physicians, among whom were many men of education and culture. Chemical reactions and processes came to be carefully studied in order to secure explanations of observations made for medical purposes. New chemical compounds were prepared for use as drugs, and thus, gradually, the domain of chemical knowledge came to be enlarged, through painstaking research and experimentation.

Having contributed much to the general advancement of the science, it seems rather strange that the iatro-chemical theory should not have held sway longer. The cause of its passing must be sought principally in the endeavors made by its devotees to explain, from its one limited point of view, all processes and phenomena of life.

As the study of vital processes, in health and in disease, became more general and more exact, adherents of the iatro-chemical school were driven to labored and oftentimes futile attempts at

explaining phenomena which were observed, and many of the claims they made could not be upheld when put to the test of practical experiment.

**Period of Transition** By the middle of the seventeenth century, thanks to the endeavors of the alchemists and the labors of the iatrochemists, knowledge of a great number of chemical facts had been amassed. The metals had been well studied; the action of heat upon many substances, organic and inorganic, had been observed; a knowledge of many salts, compounds of the alkalies with the mineral acids, had been obtained, and the time had come for an attempt at collating the numerous isolated facts and phenomena which were known.

The new era which was soon to dawn for chemistry,—chemistry as a science,—was foreshadowed at this time by the great Englishman, Francis Bacon of Verulam. Bacon was born in London in 1561; he was Lord-Chancellor of England in 1619, and died in 1626.

He taught, that truth in the experimental sciences may be ascertained only by progressive generalization—starting from some fact or principle most carefully and accurately ascertained. Each



new step must be supported by experimental evidence and proof. Only in this manner, he pointed out, may general laws be deduced and discovered. The correctness of such laws, in their turn, must be proven and demonstrated by their accounting for each and every detail of all phenomena on which they bear.

Another man whose studies and researches, dictated by a love of science for science' sake, proved of the utmost value for the progress of chemistry, was Robert Boyle. He followed the example pointed out by Bacon of Verulam, making experiments the proof and touchstone of his statements. Boyle is regarded as the founder of analytical chemistry, being the first to introduce analysis in the wet way. He contributed a great number of valuable data to physics as well as to chemistry, and was opposed to most of the teachings of alchemy as well as to the claims of iatro-chemistry.

He demonstrated that neither the four elements of Aristotle, fire, water, air and earth, nor those of the alchemists, salt, sulphur and mercury, could be regarded as the elements of chemistry. He did not advance any definite chemical theory

himself,—indeed, there were in his time not sufficient well established data to warrant such procedure,—but he rather devoted his time and talents to enriching the chemical and physical knowledge of his day by numerous well planned and carefully executed researches.

He was, for instance, familiar with the fact that air contains something which is consumed by breathing and by combustion. He confirmed the observation made in 1630, by Jean Rey, a physician of Périgord, that metals, when calcined in air, increase in weight. Boyle, moreover, noticed that when lead is transformed into litharge, in a confined and known volume of air, that the volume of this air is diminished in the process. He, however, did not perceive the true cause of this fact,—the absorption of the oxygen of the air by the lead, but attributed the increase in weight the material experienced, to the absorption of a ponderable heat-substance, which, in his opinion, united with the lead during the calcination.

Boyle's activity extended to almost all branches of chemistry. Perhaps his most important work—and his writings fill six quarto volumes—was: “ *The*

*Sceptical Chymist or Chemico-physical Doubts and Paradoxes, touching the Experiments whereby vulgar Spagyristes are wont to endeavor to evince their Salt, Sulphur, Mercury, to be the true Principles of Things.*" This book was published in 1661.

In 1665 an English chemist, Hooke, published a work, *Micrographia*, in which he discussed the similar behavior of air and of saltpetre in the supporting of combustion. He concluded, that combustion was effected by virtue of a constituent which was present in both air and saltpetre.

Theory  
of  
Combustion  
by  
Hooke  
and  
Mayow

The completion of Hooke's theory was effected by John Mayow, who pointed out in a paper, *De Sale Nitro et Spiritu Nitro-aëreo*, published in 1669, that the supporting principle of combustion is the *spiritus nitro-aërens* (oxygen) common to both air and the nitre. He also inquired into the phenomena of respiration and decided that this process was analogous to the process of combustion.

But the views of Hooke and Mayow, notwithstanding the fact that they were logical conclusions drawn from experiments carefully made, did not meet with

general appreciation nor acceptance by their contemporaries.

**Foundations of the Phlogiston Theory** The conception that the process of combustion is a process of decomposition had been entertained since the earliest times. When a substance is burned, a something, appearing to the beholder as flame, escapes from the burning body. That which remains after combustion came, quite naturally, to be regarded as another constituent of the body which had been burned.

If the experiment made by Boyle, showing the increase in weight which metals experience on heating, had been correctly understood and interpreted, or, if the work of Hooke and Mayow had been rightly valued, it is probable that the theory which we are now called on to consider—the Phlogiston Theory—would never have been advanced, or, at least, would never have enjoyed the wide popularity to which it attained.

**Phlogiston Theory** This theory was originally advanced by J. J. Becher and materially elaborated by Georg Ernst Stahl. According to its teachings all combustible bodies are compounds. All inorganic, or, as Becher calls them, subterranean bodies, are of an earthy character and have as their

fundamental constituents combustible earth, *terra pinguis*, mercurial earth and vitrifiable earth. All compound bodies contain, in varying proportions, at least two of these.

If metals are heated in the presence of air, the combustible principle escapes, and the non-combustible earth, the calx, remains. The property of undergoing combustion can therefore be possessed only by compound bodies. Substances not affected by fire,—quicklime, for instance,—were supposed to have already suffered combustion. The combustible substance, the *terra pinguis*, is not a “fire-matter,” but only a principle, and it received from Stahl the name Phlogiston, from the Greek term for combustible. Phlogiston is thus the principle of combustibility.

The phlogiston which escapes into the air is absorbed from the air by plants and passes from vegetable bodies into animal bodies. Bodies which contain phlogiston in great quantity,—coal, for instance,—also readily part with it ; calxes of metals heated with coal, take up phlogiston from the coal and are again transformed into the original metallic substance. The difference between various metals was

ascribed to the specific calx which each was supposed to contain. The colors of bodies were attributed to the phlogiston they possessed and variations in color were held to be due to changes in the quantity of phlogiston present.

Stahl, in advancing the theory of phlogiston, did not seek to deny that metals increase in weight on calcination, although he claimed that they lost phlogiston. He simply stated that phlogiston escaped on calcination, "although" an increase of weight was noticeable; he furthermore held that phlogiston was absorbed on reduction, "although" a decrease in weight was to be observed. This simply illustrates that in the earlier part of this period no regard whatever was paid to quantitative relations.

In Sweden, Torbern Bergman and Carl Wilhelm Scheele were about this time the most noted chemists of their country. Bergman's merits were especially great in the field of analytical chemistry; the credit of having pointed out the ways followed to this day in the analysis of inorganic substances belongs, in a great measure, to him. He attempted many investigations of a quantitative character and sought to determine the



amount of phlogiston in combination with various metals.

Scheele, a friend of Bergman's, was a pharmacist in Gothenburg. In his leisure hours he faithfully studied the works of Lemery, Stahl and others, and devoted much time and labor to the carrying on of chemical experiments.

His researches extended into the domains of both organic and inorganic chemistry. In the former field he gave much attention to the organic acids, in the latter he worked principally on manganese dioxide, chlorine, and baryta; that solutions of baryum-salts can serve as delicate reagents for the detection of sulphuric acid, was a discovery made by him. He also published exhaustive investigations on air and on fire, and, independently of others, discovered oxygen.

Scheele was an outspoken adherent of the phlogiston theory, but his views were nevertheless materially different from those of Stahl, declaring phlogiston to be the principal constituent of light and of combustible air.

It is quite possible—not to say probable—that both Scheele and Bergman would have abandoned the phlogiston theory if they had lived long enough



to witness the final phase of the controversy.

Among the most eminent chemists of France there were, at this time, S. F. Geoffroy, J. Hellot, Duhamel du Monceau, and P. J. Macquer. The latter, although he himself had executed quantitative analyses of mineral waters and of other substances, utterly failed to see and to acknowledge the all-important bearing which quantitative relations had on the theory of phlogiston, a theory which he sought to defend to the best of his ability.

Prominent among English supporters of the phlogiston theory were at one time, Black, Cavendish and Priestly.

Henry Cavendish was an eminent English scientist, who, through his investigations and experiments, forged the principal weapons which, in the hands of others, ultimately caused the destruction of the phlogiston theory. Yet he himself remained an ardent adherent of its teachings to his end. In 1766, he recognized hydrogen to be a peculiar gas. He believed it to be pure phlogiston and thought that it was set free from metals by acids, because acids cause the destruction of metals. Nitrogen gas

he believed to be air saturated with phlogiston, oxygen, to be air devoid of phlogiston.

Joseph Priestly also remained to the end of his life a warm defender of the phlogiston theory. He accounted for the fact that air is necessary for combustion, by stating that phlogiston, if it is to be induced to leave a body, must find some other substance, air, to combine with.

Priestley's most important discovery was made in 1774, when he prepared oxygen by heating red oxide of mercury. Although he learned that this gas supports respiration and combustion more actively than air does, yet he did not appreciate the true rôle which oxygen plays in the process of combustion.

At no time had the phlogiston theory, although so generally accepted, gone unchallenged. Remonstrances against it had been made, among others, by Boerhave, by Hoffmann and by Buffon. The latter even went so far as to express it as his conviction that phlogiston was rather more likely to exist in the minds of the adherents of the theory than elsewhere in nature.

Joseph Black was an investigator of

great originality and ability. He gave much attention to the preparation and the study of gases, a work in which he had many followers and which led to the designating of this epoch as that of pneumatic chemistry. He became a confirmed opponent of the phlogiston theory, although, for a long time, he had been one of its adherents. Contrary to the teachings of this theory, he had early turned his attention to quantitative determinations, and readily perceived that it was of prime importance to study the weight relations in chemical processes, as these only could lead to an elucidation of reactions.

By his masterly work on the alkaline carbonates, Black demonstrated that there was no such substance as phlogiston, to the absorption of which the caustic properties these carbonates acquire on treatment with caustic lime was generally ascribed.

He proved that non-caustic lime decreases in weight on being rendered caustic through ignition, and showed that this loss in weight was accounted for by the liberation of "fixed air" (carbonic anhydride).

But Black did not perceive the ultimate

logical sequences of his own discoveries. Notwithstanding his ingenious researches and their correct interpretation, it remained for another to collate all the facts and data and to effect therewith the overthrow of the Phlogiston theory.

This man was Antoine Laurent Lavoisier. Born in Paris in 1743, he received an excellent education and training, especially in the mathematics and the natural sciences.

Lavoisier and his Work

His career was equally brilliant as a scientist and as a statesman. He lost his life on the scaffold in 1794, during the reign of terror in the French Revolution.

So marked were his attainments and his services to chemistry, that an admiring compatriot of his, Adolphe Wurtz, wrote, but thirty years ago : "*La chimie est une science française. Elle fut constituée par Lavoisier, d'immortelle mémoire.*"

Lavoisier was the founder of the anti-phlogistic theory and he was the first to correctly interpret the increase in weight which metals experience on undergoing combustion. He recognized that combustion is not a process of decomposition, as the phlogiston theory maintained, but that it is a process of combination. The

substance undergoing combustion combines with a certain substance contained in the air.

Records dating from 1772 show that already at that time this question had occupied his attention. But it was only in 1775 that he enunciated his antiphlogistic theory.

He demonstrated that the amount by which the burned substance increased in weight was exactly equal to the weight of the gas absorbed. To quote his words : "The whole is greater than its part ; the products of combustion, which are heavier than the combustible bodies, cannot therefore be the elements of the latter, for, in chemical reactions, nothing is lost, nothing is created, matter being indestructible. If bodies increase in weight by burning, it is by the gain or addition of a new substance ; when, on the other hand, metallic calxes or oxides are reduced to the metallic state, the effect is due, not to the restitution of phlogiston, but to the loss of the vital air which they contain."

While the views of Lavoisier marked a great step in advance and, in fact, ushered in a new era in the history of chemical science, it must not be over-

looked, that the phlogiston theory had exercised a most wholesome influence on the evolution of chemistry.

Following upon the period of storm and stress in which chemistry first attained to the dignity of an independent science, the phlogiston theory furnished the light by which chemistry, but newly freed from the fetters and bondage of alchemy and iatro-chemistry, was guided on her way.

That this theory should, at first, have concerned itself only with qualitative phenomena must also be considered as in perfect keeping with the natural course of events. When it had taught these qualitative phenomena to be thoroughly understood and when attention came to be directed to the consideration of quantitative relations, barriers were encountered which it could not surmount.

Lavoisier first employed the term "oxygen" in 1778. Prior to that time he referred to this gas as "vital air," or, as "the air eminently adapted for the supporting of combustion and respiration." Oxygen was then also known as "dephlogisticated air."

In 1783, Lavoisier and Laplace repeated the experiments of Cavendish



and verified the latter's discovery of the compound nature of water. The experiment consisted in synthetically combining oxygen with hydrogen ("phlogiston"). Knowledge of this fact permitted Lavoisier to give a clear explanation of the phenomena of the dissolving of metals in acids and of the combination of metals with oxygen during combustion.

Lavoisier made numerous and careful researches in many directions; he was great, not only in correctly making, but also in correctly interpreting the results obtained in experiment by himself and by others, results which were, oftentimes, not properly understood nor rightly valued by the very men who had obtained them.

Having grasped the part which oxygen plays in the formation of acids, oxides and salts, he established a new chemical theory, which supplanted the views formerly held, and much of what we consider true in chemistry at the present time was first enunciated by him.

The elementary nature of the metals was pointed out, and the general idea of "simple" bodies was established. He defined an acid as resulting from the



union of a simple body, generally non-metallic, with oxygen. An oxide resulted from the union of a metal with oxygen. A salt was defined as being formed by the combination of an acid and an oxide.

“Simple,” that is to say, elementary, bodies were shown to possess the property of uniting to form compounds and the combination was shown to be effected without loss of matter. Binary compounds of the first order were formed by the union of two elementary bodies. Binary compounds of the second order were formed by the union of binary compounds of the first order.

Of course, even this anti-phlogistic theory was not perfect and the constantly increasing advance of chemical knowledge soon presented instances and phenomena which this theory could not explain nor account for. Nevertheless, it was a masterly and broad conception, and like the phlogiston theory which it supplanted, it contributed, in its day, materially to the growth and the development of chemical science.

Among the French chemists who avowed themselves followers of Lavoisier's teachings, were Guyton de Mor-

veau, A. F. de Fourcroy, and Claude Louis Berthollet.

In Germany, M. H. Klaproth was the pioneer of the anti-phlogistic theory. There was a battle royal ere the adherents of the theory advanced by Stahl and Becher surrendered to the standard bearers of the "chimie française," as Lavoisier's teachings had come to be known. General acceptance was not accorded these views in Germany until fully a decade after they had gained the day in France.

It was at Klaproth's request, that the Berlin Academy, in 1792, subjected the whole question of combustion to a rigorous test; the results of this investigation, it is almost needless to say, fully confirmed the statements of Lavoisier.

**Era of  
Quantitative  
Investigation**

The precepts set by Lavoisier, the introduction of the balance as the decisive factor in chemical research, opened to chemistry a new era which has most appropriately been termed the era of quantitative investigation.

Thus far, evolution of the science had taken place under the directing influence of some one leading thought or theory which served to mark the period which it dominated.

This, in a measure, is also true of the era which we are now about to consider. But the impulse experienced by chemistry at this time, may, in its effects, be well compared to a progressive, expanding ripple, such as is caused by a disturbance in quiet waters.

Quantitative relations were indeed the main issue, the central point, from which activity was diffused in all directions. But, so far reaching was this influence, that from now on it will be necessary to trace out, as well as may be, individual lines of thought which served to broaden the scope and reach of the science, while they themselves became merged in the general advance, the ever-widening spread of chemical knowledge.

Analytical methods had by this time been sufficiently developed—in great part through the labors of Vauquelin and of Klaproth—so as to permit of quantitative determinations.

While Bergman and Kirwan were especially active in ascertaining the quantitative composition of certain neutral salts, Klaproth and Vauquelin chiefly studied mineral substances. The great question of the day then was, whether substances, in combining to form chem-

ical compounds, combined only in one, or, at most, in a few definite proportions by weight, or whether they could and would combine in any and all proportions. The latter view was upheld by Claude Louis Berthollet. He conceded constancy in combination to only very few compounds, maintaining that most substances could unite in any proportion to form compounds. For instance, he believed that iron and oxygen could unite in any and every proportion and placed ferrous oxide and ferric oxide as the two limits. In his *Essai de Statique Chimique*, published in 1803, he attempted to explain, in analogy with Newton's theory of gravitation, the chemical changes which bodies can experience.

Lavoisier fully appreciated the fact that the combination of chemical elements takes place in definite proportions by weight. But it was Cavendish who first furnished proof of the existence of the law of combination in definite proportions. To him also belongs the credit of first introducing "equivalency," the idea and the word, into chemistry.

It was, however, the French chemist Joseph Louis Proust who gave a conclusive demonstration of the fact, that

chemical combination of bodies does not take place in any and every proportion, but that such combination occurs only in one, or at most in a few simple ratios. Proust pointed out the sources of error into which many other analysts had fallen, and in so doing based all of his conclusions on exact analytical data. His views were diametrically opposed to those of Berthollet, but they soon came to be accepted as affording the correct explanation of facts ascertained by careful observation.

The foundations of stoichiometry, the mathematics of chemistry, were laid about this time, the closing quarter of the eighteenth century, by two German scientists, Carl Friedrich Wenzel and Jeremias Benjamin Richter. Their work was, however, overlooked by most of their contemporaries and only received the appreciation it so well deserved at a later date, when general attention was given to the labors of John Dalton.

The first conception of the atomic theory—the crowning glory of Dalton's great achievements in science—was due to his perception of the fact, that whenever a definite amount by weight of one substance combines in varying proportion

Atomic  
Theory

with another substance, the proportions in which combination takes place bear a simple ratio to one another.

The view that matter consists of minute and indivisible particles had been held for many centuries—even, as will be remembered, by the Greek philosophers of old. The idea that chemical combinations were due to the coalescing of unlike particles had been advanced by Kirvan in 1783, and by Higgins in 1789.

It can therefore not be claimed that the conception of the atomic theory originated with Dalton. However, it was he who first impressed upon this theory — a theory dealing with the constitution of matter—the *quantitative* aspect.

He held that different weights characterize the atoms of the various elements ; that each element is composed of similar atoms of definite weight, and he expressed in his theory the law of multiple proportions : if two elements combine in different proportions, the relative amounts of the one which combine with a fixed amount of the other are simple multiples of each other. As a sequence of his considerations it follows that the total atomic weight of a compound (the



molecular weight), is equivalent to the sum of the atomic weights of its constituents.

The first reference to his atomic theory was made by Dalton in a paper read before an English philosophical society, October 23d, 1803, when he alluded to an inquiry he was making "into the relative weights of the ultimate particles of bodies." The first published account of Dalton's Atomic Theory is to be found in the work of one of his friends, Thomas Thomson, in the third edition of the *System of Chemistry*, which appeared in 1807. *A New System of Chemical Philosophy*, which issued from Dalton's own pen in the following year, contains a full exposition of his ideas. These views of the quantitative relations governing chemical compounds, practically form the basis of our chemistry of to-day.

Introduction and futherance of Dalton's atomic theory was brought about chiefly by Thomson, by Wollaston, and by the great Swedish chemist, Berzelius. Jöns Jacob Berzelius had been forcibly impressed with the writings of Richter, previously alluded to, and had entered upon an extensive investigation of cer-



tain salts in order to test the validity of Richter's views and claims.

When Dalton's theory came to his knowledge, the analytical results which Berzelius had himself obtained bore witness to the correctness of Dalton's reasoning. Painstaking experimental corroboration of Dalton's atomic theory must ever be counted as one of the most valuable contributions which Berzelius has made to chemistry.

#### **Law of Volumes**

The truth of Dalton's Atomic Theory was also borne out by the discovery, made in 1805, by Alexander von Humboldt and by Gay-Lussac, that two volumes of hydrogen combine with one volume of oxygen to form water. This ultimately led to the determination of the law which governs the volume combination of gases, the so-called Law of Volumes, announced by Gay-Lussac in 1808. This law holds that the ratio in which gases combine by volume is always a simple one, and that the volume of the resulting gaseous product bears a simple ratio to the volumes of its constituents. Dalton at first took issue with Gay-Lussac's statements and reasoning, for the latter made no distinction between atoms and atom-complexes, now termed

molecules. But in 1811 an Italian physicist, Amadeo Avogadro, succeeded in showing, by establishing a difference between *molécules intégrantes* and *molécules élémentaires*, integral and elementary molecules, that the observations of Gay-Lussac and the teachings of Dalton were in full accord. Our term molecules corresponds to the first of these conceptions, our term atoms to the second. Molecules are regarded as composed of indivisible atoms. Avogadro was the first to demonstrate that equal volumes of all gases contain an equal number of molecules.

Avogadro's Hypothesis

Ampère's name is often linked with Avogadro's theory, but the essay of the former did not appear until three years after Avogadro had made his announcement. Yet it was only in 1858, through Cannizzarro's able presentation of Avogadro's work, that the latter received the recognition which it so justly deserved.

An hypothesis was advanced in 1815 by an English physician, Dr. Prout, to the effect that the atomic weights of all elements are whole numbers and that the elements themselves are condensation-products of hydrogen.

Prout's Hypothesis

While the claim that the atomic weights are simple multiples of the atomic weight of hydrogen, has long ago been completely disproven by exact analytical determinations, yet it must not be overlooked that Prout's claims gave the impetus to many most valuable investigations which have been carried out with the utmost refinement of analytical skill. It is through such most accurate determinations of some of Nature's constants, that chemistry has justly gained the distinction of ranking as one of the exact sciences.

**Law of  
Dulong  
and Petit**

In 1819, Dulong and Petit discovered the fact, that the specific heat of an element is inversely proportional to its atomic weight, or, as they expressed it, that the atoms of the different elements have the same capacity for heat.

Specific heat is defined as the ratio of the amount of heat required to raise a given weight of a body one degree in temperature, compared to the amount of heat required to raise the same weight of water to the same extent. As the average value of the product of the specific heat of an element by its atomic weight is about 6.4, a simple division of this constant by the specific heat of the

element in the solid state, gives approximately the weight of an atom of that element, thus affording valuable indications in determining these very important values, the atomic weights.

Mitscherlich's theory of isomorphism, that compounds of analogous composition and containing the same number of atoms assume the same form in crystalizing, was, by Berzelius, considered to be of value in the determination of atomic weights. Time, however, has proven that the results which this theory has yielded are deserving of less credit and credence than was once accorded them.

Experiment having conclusively shown that in numerous instances substitution of one element for another could be effected, the relative amounts of the different elements which could thus replace each other naturally called for consideration. The term equivalent was applied to the smallest amount by weight of an element which could combine with or replace the unit weight of hydrogen. The weight of an atom, the atomic weight of an element, must then be identical with or must be some multiple of this value.

**Isomorphism**

**Chemical  
Equivalents and  
Valence**

For a time considerable confusion

reigned in this question of atomic weights and chemical equivalents, until, chiefly through the researches of Edward Frankland on the organo-metallic substances, the idea of valence was introduced.

The terms valence, valency, or quantivalence designate the degree of combining power of an atom of any element, compared with the combining power of an atom of hydrogen selected as unity. According to the degree of the combining power thus defined, the elements are classed as monads, dyads, triads, etc. This means that one atom of an element can combine with or replace one, two, three or more atoms of hydrogen, as the case may be.

The relation between the chemical equivalent and the atomic weight of an element is expressed by the formula : the atomic weight of an element is equal to the product of its chemical equivalent by its valence. Thus, in the case of monads, atomic weight and chemical equivalent are identical; in dyads, the atomic weight is equal to twice, in triads it is equal to three times the chemical equivalent of the element.

The importance of exact determina-

tion of the atomic weight values of the elements will be appreciated, when it is remembered that these values may be regarded as the constellations by which the courses of chemistry are shaped.

## Atomic Weights

One of the most eminent chemists who ever engaged in the determination of atomic weights was Jean Servais Stas, a Belgian. He was a pupil of Dumas ; his results, based on experiments made with larger quantities of material than are usually employed in such determinations, furnished much of the evidence that disproved the hypothesis of Prout.

Among American chemists who have achieved especial distinction in work along these lines, there should be mentioned Morley, Clarke and Richards. Since 1893 an American Committee on Atomic Weights has issued,—through the pen of F. W. Clarke,—annual reports on these values.

The table of Atomic Weights given on page 65 has been recommended for general adoption in analytical practice by a commission consisting of H. Landolt, W. Ostwald and K. Seubert. This representative commission was appointed by the German Chemical Society.

## Table of Atomic Weights

Its members recommend that :

1. The atomic weight of oxygen be taken as 16.000, and that the atomic weights of the other elements be calculated on the basis of their combining ratios with oxygen, directly or indirectly determined.

2. The following atomic weights of the elements be adopted in practice, as they are probably the most correct values known at the present time. (See table.)

These numbers are, as a rule, given only with so many decimals that even the last one may be regarded as accurate. In consequence, the atomic weights determined by Stas, in which the errors amount to from 3 to 6 units in the third decimal, are given with two decimals ; the other atomic weights, which have been more accurately determined, are given with one decimal, and those less accurately determined are given without decimals. Exceptions to this rule have been made only in the cases of nickel, bismuth and tin, marked with an asterisk in the table.

In the case of nickel this was done in order to emphasize the difference between the atomic weights of cobalt and nickel, although in both values there



| Name.           | Symbol. | Atomic Weight. | Name.              | Symbol. | Atomic Weight. | Name.           | Symbol. | Atomic Weight. |
|-----------------|---------|----------------|--------------------|---------|----------------|-----------------|---------|----------------|
| Aluminium....   | Al      | 27.1           | Helium (?).....    | He      | 4              | Rubidium .....  | Rb      | 85.4           |
| Antimony .....  | Sb      | 120.           | Hydrogen.....      | H       | 1.01           | Ruthenium ...   | Ru      | 101.7          |
| Argon (?).....  | A       | 40.            | Indium .....       | In      | 114.           | Samarium(?)..   | Sa      | 150.           |
| Arsenic.....    | As      | 75.            | Iodine.....        | I       | 126.85         | Scandium .....  | Sc      | 44.1           |
| Barium.....     | Ba      | 137.4          | Iridium.....       | Ir      | 193.0          | Selenium .....  | Se      | 79.1           |
| Bismuth.....    | Bi      | 208.5*         | Iron .....         | Fe      | 56.0           | Silicon .....   | Si      | 28.4           |
| Boron .....     | B       | 11.            | Lanthanum .....    | La      | 138.           | Silver .....    | Ag      | 107.93         |
| Bromine.....    | Br      | 79.96          | Lead .....         | Pb      | 206.9          | Sodium .....    | Na      | 23.05          |
| Cadmium .....   | Cd      | 112.           | Lithium .....      | Li      | 7.03           | Strontium.....  | Sr      | 87.6           |
| Cæsium.....     | Cs      | 133.           | Magnesium .....    | Mg      | 24.36          | Sulphur .....   | S       | 32.06          |
| Calcium .....   | Ca      | 40.            | Manganese .....    | Mn      | 55.0           | Tantalum.....   | Ta      | 183.           |
| Carbon.....     | C       | 12.00          | Mercury .....      | Hg      | 200.3          | Tellurium ..... | Te      | 127.           |
| Cerium .....    | Ce      | 140.           | Molybdenum.....    | Mo      | 96.0           | Thallium .....  | Tl      | 204.1          |
| Chlorine.....   | Cl      | 35.45          | Neodymium(?)....   | Nd      | 144.           | Thorium.....    | Th      | 232.           |
| Chromium.....   | Cr      | 52.1           | Nickel .....       | Ni      | 58.7*          | Tin .....       | Sn      | 118.5*         |
| Cobalt.....     | Co      | 59.            | Nitrogen.....      | N       | 14.04          | Titanium.....   | Ti      | 48.1           |
| Columbium....   | Cb      | 94.            | Osmium .....       | Os      | 191.           | Tungsten .....  | W       | 184.           |
| Copper .....    | Cu      | 63.6           | Oxygen .....       | O       | 16.00          | Uranium .....   | U       | 239.5          |
| Erbium (?)..... | Er      | 166.           | Palladium.....     | Pd      | 106.           | Vanadium .....  | V       | 51.2           |
| Fluorine.....   | F       | 19.            | Phosphorus .....   | P       | 31.0           | Ytterbium ...   | Yb      | 173.           |
| Gallium.....    | Ga      | 70.            | Platinum.....      | Pt      | 194.8          | Yttrium.....    | Y       | 89.            |
| Germanium...    | Ge      | 72.            | Potassium.....     | K       | 39.15          | Zinc .....      | Zn      | 65.4           |
| Glucinum .....  | Gl      | 9.1            | Præsdodymium (?).. | Pr      | 140.           | Zirconium.....  | Zr      | 90.6           |
| Gold.....       | Au      | 197.2          | Rhodium .....      | Rh      | 103.0          |                 |         |                |

may be possible deviations of  $\pm 0.2$ . The true atomic weights of bismuth and tin are not correct to a certainty, to within 0.1. The value of hydrogen is 1.008, correct to within 0.001, but the approximation of 1.01 has been regarded as permissible for the requirements of practice, as it involves an error of only one-fifth of one per cent. The values given for the elements marked in the table with interrogation points are not necessarily exact within whole units of the atomic weights assigned.

Chemistry has been exceptionally favored in the last year or two by the discovery of new elements.

A study of argon and helium, constituents of our atmosphere, has led to the discovery of several other new elementary substances. Thus, Ramsay and Travers have recently isolated from liquefied argon three new bodies, krypton (hidden), neon (new) and metargon.

All of these are gases and occur in the earth's atmosphere in minute amounts; neon, for instance, only to the extent of about one part in forty thousand parts of air. There seems to be some doubt as to whether metargon is or is not an element; it is said to have about the

same atomic weight as argon, but is possessed of different properties. It is a solid at the temperature of liquid air. Quite recently another new gas has been added to those previously obtained from liquefied argon ; xenon is the name that has been assigned to it.

In July, 1898, Professor Nasini of Padua announced that he had, while studying the gases emanating from the Solfatara di Pozzuoli and the fumarole of Vesuvius, discovered a new gaseous element. Coronium is the name given to this substance, now first found upon our earth, but which, on the evidence of the spectroscope, has for some time been known to exist in the corona of the sun.

At the meeting of the American Association for the Advancement of Science, in 1898, Charles F. Brush announced the finding of a new gas, which he had extracted from glass at low pressures. This new body is said to occur in the air and to be easily absorbed by numerous substances, especially by glass. On account of its peculiar properties—its high molecular velocity, 105 miles per second, and its very low density, 0.0001 if hydrogen be taken as 1.0—Brush suggested

that this might possibly be the ether, the existence of which is assumed in physics. The name which he proposed for this supposedly new element is, etherion. However, the possibility of this substance being water-vapor has been recently suggested by Sir William Crookes and further developments must be awaited before the question at issue can be determined.

The investigator last named has isolated from yttria a body to which he has given the name monium, from the Greek word for "alone." Its atomic weight will probably be about 118 and it is said to enter readily into chemical combination with other elements.

**Electro-  
Chem-  
ical  
Theory** Within the past century and a half chemistry has witnessed the birth and the growth of a number of theories and hypotheses, which, while they have all exercised some influence, one way or another, on the development of our science, can here claim but a passing reference.

Of these the first to call for attention is the electro-chemical theory of Berzelius. Fundamentally this was based upon observations made by Sir Humphry Davy ; it held that every atom was endowed with certain amounts of both

positive and negative electricity. These electrical charges were supposed to be accumulated on different parts of the atoms, giving rise to negative and positive poles. It was the preponderance of the one or the other kind of electricity which, it was believed, determined the electrical character of an atom. Atoms electrified in an opposite sense would be attracted to, atoms bearing charges of the same kind would be repelled from one another. On the combination of atoms bearing unlike charges, neutralization of the same would result.

Berzelius suggested the existence of compound atoms ; this view of the structure of matter came to be known as the dualistic theory. It was closely allied to the electro-chemical theory and is best considered in connection with the latter, which was, for almost twenty years, the dominant theory of chemistry.

Dual-  
istic  
Theory

Reference, however brief, must be made of the important results secured by Michael Faraday in establishing the quantitative relations which obtain when electrical power is made to do chemical work. Faraday conceived the idea of sending an electric current successively through a series of cells which contained

Fara-  
day's  
Law

different solutions which would permit the passing of electric currents. Such solutions are termed electrolytes, and his observations determined that an electric current of a given strength will set free *equivalent* quantities of the constituents of different electrolytes. His law of constant electrolytic action was enunciated in 1833; its discoverer believed that it would prove a valuable aid in the determination of atomic weights.

**Attacks  
on the  
Atomic  
Theory**

Dumas and other French chemists, while engaged in studying the atomic weights of the elements, were led, through their determinations of the specific gravity of vapors at high temperatures, to seriously doubt the validity of the law of volumes.

It chanced that Dumas worked chiefly upon substances the molecules of which were complex, a fact, however, unknown to the experimenter. Finally, and in consequence of his results, Dumas questioned the truth of the law of Avogadro. Other evidence also seemed to point to the untenability of Avogadro's conclusions, and Leopold Gmelin, a pupil of Berzelius, a most eminent chemist and the author of several important works on chemistry, was led to abandon the atomic

theory completely. Gmelin held that, as a rule, the proportions in which substances could combine were unlimited in number. He issued a table of equivalents, which might be styled a list of combining numbers. When a choice of equivalents seemed permissible, the lowest value was selected. His views on these matters met with general favor and were incorporated in many text-books, even as late as thirty years ago.

The theory of radicals can primarily be traced to the writings of Lavoisier ; after passing through various modifications it attained to prominence about the year 1838, having received its greatest impetus from an investigation undertaken in 1832, by Justus von Liebig and by Wöhler, "On the Radical of Benzoic Acid," which showed the existence of an atomic group—benzoyl—in oil of bitter almonds and its derivatives. As this theory, as well as the dualistic theory, involved the conception of atoms, both contributed to restore to favor Dalton's views, which had once been held in great esteem.

An attempt to apply the theory of radicals to organic compounds resulted in the so-called "Ætherin" theory,

Theory  
of  
Radicals

Ætherin  
Theory



which was advanced by Dumas and Boullay. Olefiant gas, for which Berzelius suggested the name "ætherin," was regarded as a constituent of the alcohols, the sugars and other substances, these bodies being in their composition compared to the compounds of ammonia.

**Substitution  
Theory**

Berzelius' theory of dualism was disposed of primarily through a research on wax-candles by Dumas, an investigation in which the principle of substitution of chlorine for hydrogen was discovered and proven. Dumas further explained by his theory the formation of chloroform and of chloral, which bodies Liebig had obtained by the action of chlorine on alcohol.

**Nucleus  
Theory**

Auguste Laurent, finding that Dumas' law of substitution did not afford a valid interpretation of all the data observed, suggested his nucleus theory; this was an outgrowth of the theory of radicals, but, instead of claiming the existence of atomic groups of stable and unchangeable composition, Laurent's views held that such groups admitted of changes by the substitution of equivalents.

**Unitary  
Theory**

Notwithstanding the efforts of Berzelius to uphold his dualistic theory, to achieve which he evolved the hypothesis

of conjugate compounds, and notwithstanding the labors of Kolbe, which were directed to the same end, Laurent and his friend Carl Gerhardt carried the day with their unitary theory. This latter maintained that the nature of a molecule was determined by the nature, the number and the arrangement of the atoms which formed it, and furthermore, that these atoms were capable of being exchanged for—that is, were capable of being replaced by—other atoms.

Laurent and Gerhardt introduced the theory of types. They originally recognized three types: water, ammonia and hydrochloric acid, and in their classification they sought to refer all compound substances to one or the other of these as model forms. The continued discovery of new bodies, however, soon made the creation and adoption of other additional types a necessity, and the type-theory ere long grew to be unwieldy and cumbersome.

The first half of the nineteenth century witnessed various attempts to trace relations between the atomic weights of elements and some of their properties. Possibly the first instance of this kind which received general attention was

Theory  
of  
Types

The  
Periodic  
Law

the work done by Döbereiner, who, in 1829, found that certain elements have atomic weights which are approximately the mean of the atomic weights of two other elements closely resembling them in their properties. Döbereiner also ascertained that groups of three could be formed of some elements whose atomic weights were almost the same and which exhibited close analogies in most of their properties. A systematic classification of the elements, basing on the similarity of their properties, was an ardent wish of this investigator. But, of course, ere this could be accomplished, accurate determinations of the atomic weights of all elements were imperative.

The periodic law, which holds that the properties of the elements are periodic functions of their atomic weights, was established chiefly through the labors of Newlands, Mendeléeff and Lothar Meyer.

It seems that the first communication Newlands made on this subject was published early in 1863. In the following year he issued a list of the elements in the order of their atomic weights; the announcement of the periodic law by the two other investigators named was made in 1869.

It is, however, the distinctive merit of Mendeléeff to have pointed out that the value of any given property of an element is practically an average of the values of the same property of two other elements which immediately adjoin it, when the elements are arranged in a table progressively, in the order of their atomic weights.

Moreover, this distinguished Russian chemist, from a close study of his tables illustrative of the periodic law, predicted the existence and the properties of certain elements not then known. The discovery of Gallium, of Scandium and of Germanium, made respectively in 1875, 1879 and 1886, brilliantly fulfilled the prophecy of Mendeléeff.

Neon, "the new one," furnishes the most recent instance of an element sought for because the probability of its existence seemed indicated by a gap in a periodic arrangement of the elements. It was discovered in and isolated from air by William Ramsay, the well-known English chemist, whose name is also linked with that of Lord Rayleigh in the discovery of argon and of helium.

An arrangement of the elements into groups and series, based on the principles

indicated, and a close study of their relations, have led, not only to a prediction of the existence of undiscovered elements, but have, in some cases, also proved of great value in the detection of erroneous atomic weights.

The periodicity of many chemical and physical properties of the elements—for instance, of valence, of electro-chemical and magnetic powers, the toxic properties of metals, and so forth—has received careful attention. Through studies of this kind it has become possible, in some instances, to predict the action of certain medical preparations, their composition and molecular structure being known.

A tracing out of such and similar relations is certainly of great interest. Of recent years, experienced teachers of chemistry have found a presentation of the fundamental data of their science based on the periodic law, of great didactic value. While the periodic law, so called, cannot as yet give a logical accounting of all phenomena, it seems beyond question that it is to-day one of the most important theories of chemistry.

The valency of the element carbon had been studied and determined by Frank-

land. His conclusion that carbon is tetra-valent was confirmed by the independent investigations of August Kekulé, who, as a result of his researches into the manner of combination of carbon atoms *inter se*, laid the foundations of the important chain-theory, which has proved of great value in the realm of organic chemistry.

Study of the structural arrangement of molecules, which resulted in the theory of the grouping of atoms in space, was initiated by the labors of Louis Pasteur, on the phenomena of isomerism exhibited by the tartaric acids.

The work of Johnannes Wislicenus on lactic and sarcolactic acids, carried on in 1873, foreshadowed the teachings of Van't Hoff and Le Bel, who, in 1874, almost at the same time but independently of one another, formulated the principles of stereo-chemistry.

Van't Hoff had elaborated his ideas with the object of explaining the property which many carbon-compounds, when in solution, possess of rotating the plane of polarized light. Le Bel, who followed Van't Hoff's announcement with his own conclusions on the subject but a few months later, was likewise led to his



conceptions by a study of the optical behavior of certain solutions. A treatise by F. W. Clarke, *Chemistry of Three Dimensions*, published in 1875, likewise emphasizes the conclusion that all molecules must be tri-dimensional.

Thus far the compounds of carbon and the compounds of nitrogen have received most attention from those who have given special care to the developments of stereochemistry, but chemistry in general has undoubtedly been enriched in many ways through the stimulation given by this new departure from the old and well beaten tracks.

The  
Lan-  
guage of  
Chem-  
istry

Development of the language of chemistry has of course been conditioned by and kept pace with the evolution of the science. The earliest terms employed in chemistry were, as a rule, suggestive of the origin of the substances which they denoted. The term *sal*, for instance, was applied since the earliest times to all substances having a salty taste. About the eighth century the attempt was made to distinguish between different substances having a salty taste, by adding a word descriptive of the origin of such substance ; thus, common salt was called *sal maris*, salt of the sea.



The thirteenth century witnessed the free use of certain symbols to denote some of the metals ; thus, gold, called *Sol* by the alchemists, was by them depicted by a circle with a dot in its center ; silver, in their language *Luna*, was represented by a crescent ; copper, which they termed *Venus*, was denoted by a circle to the bottom of which a small cross was attached.

The original and true meaning of these symbols is not known ; many and fanciful, however, have been the explanations suggested. For instance, it has been supposed that the symbol chosen for Venus represented a hand-mirror.

Some of the alchemists saw in these symbols an indication of the chemical properties of the metals they denoted. Thus, the circle was held to illustrate perfection of the metallic condition, the semi-circle an approximation to this state ; however, an attempt to trace the various signs which were gradually introduced into the science and the numerous transmutations which they suffered in the course of time, would carry us far beyond the purpose and the limit of these pages.

Reference by name only can here be

made to the systems of symbols used by Geoffrey, by Bergman, by Dalton, by Berzelius, by Hassenfratz and Adet.

The last named was specifically intended to accompany the chemical nomenclature devised by Lavoisier, De Morveau and colleagues, the system which is the foundation of the one employed at the present time.

Within the past decade various attempts have been made to agree upon some method of chemical nomenclature and notation which should meet with universal acceptance. Concerning the names and the symbols of the elements, those known to the ancients mostly retain their original appellation. In naming elements the discovery of which belongs to a later date, it has become customary in the case of metals to assign the termination *um* or *ium* to the name selected ; in the case of non-metals, to make the ending of the appellation *ine*, *on* or *gen*. The choice of the name of an element rests, of course, with its discoverer. In some cases the names of the planets have been used for the purpose ; thus, Mercury, Tellurium, Selenium own as their sponsors respectively Mercury, the earth and the moon.

In other instances the patriotism of the discoverer has immortalized the name of his country by bestowing the same upon the newly found substance. Columbium, Germanium and Gallium may be cited in illustration. The names of deities have also been pressed into service to this end; thus, Thorium from Thor, one of the gods of Norse mythology.

Sometimes the name which an element bears has been suggested by some distinctive property which it possesses. Iridium is derived from the Latin word *iris*, a rainbow; Iodine from the Greek term for the violet; Barium from the same language, from the word which denotes weighty.

The names of chemical substances, of elements and of compounds, are frequently indicated by symbols. As a rule the symbols which denote the elements are indicative of their names and usually consist of the initial, or of the initial and some other letter of such name. Thus, carbon is designated by the letter C, calcium by the letters Ca, and copper by the letters Cu, these last being taken from the Latin appellation of copper, *cuprum*.

It is an important matter to remember

that the symbol of an element stands not only for its name, but represents at the same time a definite amount of the element—the weight of one atom.

An atom is defined to be the smallest quantity of matter which can enter into chemical combination. If it be desired to indicate more than one atom, the requisite numeral is placed with the symbol. The symbols of compounds, usually termed formulae, are simply combinations of the symbols of the elements forming the compound and of numerals which indicate the number of atoms of the elements which are present in the compound ; thus, water is a compound of two gases, hydrogen and oxygen. The smallest amount of water, which can exist as such, contains two atoms of hydrogen and one atom of oxygen ; its formula is therefore  $\text{H}_2\text{O}$ .

By a simple and ingenious system of terminals and of prefixes, taken in part from the Latin and the Greek languages, chemists are enabled to have the name of a compound indicate to a certain extent its chemical composition.

The chemical composition of a compound can be concisely expressed in a formula ; from the chemical formula of a

substance, one versed in the language of chemistry can usually designate by name the substance represented.

When elements or compounds are subjected to influences which cause them to undergo changes, the reactions can be indicated by the aid of symbols and formulae. As matter is indestructible, nothing is lost in these reactions, and such expressions of change must therefore, of necessity, be equations; they are termed chemical equations. Chemical equations are known respectively as synthetic, analytic, and metathetic, as they represent the formation of substances by the union, the decomposition, or the interchange of constituents.

It was during the epoch of iatro-chemistry that chemistry was first taught at the universities. At first the teaching of this subject was included in the lectures on medicine delivered by professors of that faculty. The first lecturer who treated chemistry as an independent subject was a German, Johann Hartmann. He spoke at the high school at Marburg, in the first quarter of the seventeenth century.

Didactic  
Chem-  
istry

University instruction in laboratory practice was established much later,—in

fact, only towards the end of the century last named; the first public chemical laboratory for purposes of instruction was founded in 1683, by the council of Nüremberg; it was situate at Altorf, and its first director was Johann Moritz Hofmann.

Lectures on chemistry, illustrated by experiments to serve didactic purposes, were introduced in France about one hundred years ago. In England, Sir Humphry Davy is credited with making this kind of instruction popular, and other countries soon followed the novel practice. Modern methods of laboratory instruction in chemistry are generally believed to have been inaugurated by Justus von Liebig; at least it is certain that his laboratory was one of the first to be established, and the same has certainly made its influence felt all over Germany and far beyond her borders.

**Manuals  
of Chem-  
istry**

One of the earliest works on chemical subjects which can in any way be looked upon as a text-book, is an English publication, *Compound of Alchymie*, which was prepared by George Ripley, about the year 1471.

In an introduction in verse, with which he prefaces his volume, he, after

informing his readers of his intentions, outlines the table of contents :

“ But into Chapters thys Treatis I shall devyde,  
In numbre twelve, with dew recapytulatyon ;  
Superfluous rehearsalls I lay asyde,  
Indendyng only to give trew informatyon  
Both of the theoryke and practycall operatyon:  
That by my wrytyng who so wyll guyded be,  
Of hys intende perfyctly speed shall he.”

Agricola's work, *De re metallica*, published in 1546, contains a good *resumé* of the art of metallurgy as it was understood at that time, but the first general treatise on chemistry is probably the *Alchymia*, by Andreas Libau, or Libavius, as he was often called. This work, published in 1595, is divided into two sections; the first of these describes chemical operations and apparatus and contains directions for the regulation and the application of fire. The second part of the book treats of the preparation and the properties of chemical substances and compounds. No consideration is given in this book to theoretical discussions.

Quite a number of works on chemistry were issued in the seventeenth century; some of these laid special stress on medical chemistry, others were more



general in their character. Of these, possibly the *Cours de Chymie*, published by Nicolaus Lemery in 1675, and the *Chymia Philosophica*, by Jacob Barner, which was issued in 1689, were the most important.

The standard work of Hermann Boerhave, *Elementa Chemiae*, first published in 1732, consists of two parts, the first of which deals with the theory, the second with the practice of chemistry. As representative works of the phlogistic and of the anti-phlogistic schools respectively, there might be mentioned Georg Ernst Stahl's *Fundamenta Chemiae Dogmaticae et Rationalis* and Antoine Laurent Lavoisier's *Elements de Chimie*.

The original of the *Lehrbuch der Chemie*, by Berzelius, the first volume of which appeared in 1808, experienced many editions and also a translation into the German tongue. This work remained an authoritative work during the greater part of the first half of this century.

Among the standard English manuals of chemistry which this century has produced, probably none outranks the *Treatise on Chemistry*, by Roscoe and Schorlemmer. Of English works of reference in this science, the *Dictionary of Chemistry*, by Henry Watts, and the

revised edition of this publication by Morley and Muir, undoubtedly hold first place.

However, it would be a great and profitless task to attempt here a recital of the wealth of chemical literature—a store-house of treasure—to which all civilized nations of the world have contributed. Some conception of its extent may be gained by learning that *A Select Bibliography of Chemistry*, 1492-1892, prepared by the distinguished American bibliographer and chemist, H. Carrington Bolton, and published in 1893, enumerates no less than twelve thousand and thirty-one titles of independent books and their translations.

Of these, four thousand five hundred and seven titles are credited to the German, two thousand seven hundred and sixty-five to the English, and two thousand one hundred and forty-one to the French language.

Two supplements of this most valuable work add respectively about six thousand and eight thousand titles to the number above given. The latter of these volumes is limited entirely to the recording of dissertations, while a *Catalogue of Scientific Periodicals*, in which of course many

journals on chemistry are included, and which has also issued from the pen of Professor Bolton, lists no less than eight thousand six hundred titles.

Chem-  
ical  
Analysis

Appreciation of the wide domain legitimately open to chemistry brought with it application of its teachings and principles in many ways to many problems. The directing influence in such adaptations was, of course, chemical analysis, which has for its object the resolving of substances into, and a determination of, their components.

With a perfecting of the methods of chemical analysis, a more accurate knowledge and understanding of the composition, the properties and the behavior of the substances analyzed was gained. In consequence, new processes of manufacture could be devised, those in existence could be more carefully followed, controlled and improved, and thereby, in many instances, a lowering in the cost of production effected.

Notwithstanding the great importance of analytical chemistry, the purely scientific aspect of this branch of the science had, up to the present decade, been sadly neglected, although in its practical aspects and details analytical chemistry

had received great attention and care for many years. It was Wilhelm Ostwald's work, *The Scientific Foundations of Analytical Chemistry*, published in 1894, which marked a pioneering venture into this inviting but theretofore practically unexplored domain.

In chemical analysis distinction is made between proximate and ultimate analysis. Aim of the former is the determination of individual groups existing in a substance. Thus, milk consists of water, fats, albumenoids, sugar and salts; a proximate analysis of milk would involve the determination of these constituents, as such.

Ultimate analysis is concerned with the determination of the individual elements which enter into the constitution of a substance. In the illustration cited, for instance, it would be the task of ultimate analysis to determine the carbon, the hydrogen, the oxygen and all other elementary components of the substances which have been enumerated as constituents of milk.

Methods of chemical analysis must of course be adapted to the physical character of the bodies to which they are applied. Gases, liquids, solids, call for

different modes of treatment, which must be especially suited and adapted to their respective properties. It is a frequent practice of the analyst to bring a body from one state of aggregation into another, for instance, to transform a solid substance into a solution, before subjecting it to an analytical examination.

When the object of an analysis is only the ascertaining of the constituents of a substance,—that is to say, when no attempt is made to determine how much of each constituent is present,—the process is designated one of qualitative analysis.

If, however, a knowledge of the amounts in which the constituents are present be desired, the analysis assumes the character of a quantitative determination. In practicing the latter, distinction is made between gravimetric analysis and volumetric analysis, according to the manner in which the quantitative determination is effected. If the amounts of substances are ascertained by weighing, the work is termed gravimetric; if by the use of measured volumes of reagents, the process is designated one of volumetric analysis.

It has already been mentioned that the era of quantitative analysis was intro-

duced through the balance coming into general use in chemistry. The refinement and degree of accuracy to which many modern chemical determinations can lay claim is marked, and this is, in no small measure, due to the exercise of the mechanical ingenuity and skill which are nowadays bestowed upon the manufacture of analytical balances.

For many centuries, and in fact up to within a few centuries, fire was considered to be the principal agent for the bringing about of chemical changes. How firm a hold this belief had on the minds of workers in the science, may be inferred from a motto placed in a textbook on chemistry that was published in 1663 :

*Sine igni nihil operamur.*

Although fire played so prominent a rôle in the doings of the earlier investigators, yet the measurement of temperatures was but roughly approximate and very crude until Boerhave demonstrated the necessity and importance of employing thermometers in many chemical investigations.

The construction of thermometers of the present type, containing a fluid, was first carried out about the middle of the

seventeenth century, by members of the *Accademia del Cimento*. Fahrenheit, in 1714, employed mercury for the filling of thermometers, and Boerhave, in his famous treatise on chemistry, expressed the boiling- and the melting-points of substances in degrees Fahrenheit.

To secure the heat needed for their operations, the alchemists and their successors in the science paid great attention to the form and to the construction of their furnaces. Among the fuels used were wood, wood-charcoal, coal, peat, alcohol and oil. For the obtaining of their highest temperatures they employed burning glasses, turning to the sun for the required energy. Some important additions to chemical knowledge resulted from so practical a sun-cult ; combustion of the diamond is, for instance, said to have been first accomplished by the help of the sun's rays.

The obtainment of high temperatures by the use of oxygen was introduced by Priestley, who caused a jet of this gas to impinge on a glowing coal. The first apparatus in which hydrogen was burned in oxygen, was constructed by Hare, in 1801.

The two principal forms of dry analy-



sis which are practiced to-day are blowpipe work,—which occupies itself with the behavior of substances under varying conditions of flame and generally in the presence of reagents,—and assaying, which is principally concerned with the determination of ores and metals by the processes of smelting and cupellation.

The blowpipe, which was originally used for the soldering of metals, was first employed for the testing of minerals by Cronstedt and Engestrom. Bergman and one of his assistants, Johann Gottlieb Gahn, studied thoroughly the behavior of different substances and reagents under the flame of the blowpipe. Their work on the testing of minerals by the blowpipe was published in 1779, and was the first treatise on this important branch of chemical analysis. Gahn's labors in this field continued for many years; after Berzelius had become his co-worker, the latter published a book on their methods and results, which experienced translation into several languages.

An Englishman, William Hyde Wollaston, was another adept in the use of the blowpipe. He was a man of considerable ability and attainments, but perhaps his greatest achievement was the

working out of a method for the refining of platinum, a method which could be applied on a manufacturing scale and which made possible the introduction of platinum vessels in the chemist's laboratory.

Assaying and blowpipe-work, or docimacy, as it is often termed, are entirely distinct from the principles and methods of "wet" analysis, a term often used to specify the working with solutions.

This latter important branch of chemistry received its first potent impulse through the labors of Bergman. His directions for the analysis of mineral substances, which appeared in 1777 and the years following, were probably the first directions of the kind published. In these he taught how minerals can be brought into a state of solution, by powdering them finely, by fusing them with the proper reagents and by then subjecting them to the action of acids.

While Bergman was thus probably the first to break ground in this new field, Martin Heinrich Klaproth was the one who first brought chemical analysis into systematic shape and who laid the foundations of that important structure, analytical chemistry, to the perfection of

which so many able chemists have since given their best endeavors.

One of the greatest benefits bestowed upon chemistry by Klaproth was the practice, which he was the first to introduce, of recording the results of his analyses exactly as he obtained them.

As our mistakes should be stepping-stones to the truth, the value of Klaproth's procedure is patent. Thus, if the results of a complete analysis of a substance should fall below 100 per cent, to which they should figure, and if the difference should prove too great to be accounted for on the plea of permissible experimental error, then search would naturally be instituted for the cause, duplicate analyses would be made, and the work, if faulty, corrected. If the duplicate analyses agreed, then there would be reason to suspect some constituent before not determined. Analysts prior to Klaproth did not pursue this course, and thereby they undoubtedly passed by many data which they could have secured.

Klaproth left the imprint of his ability not only on analytical methods, but he likewise perfected much of the apparatus used in chemical manipulations; the

introduction of silver crucibles, for instance, was due to him ; in fact, so great were his merits in these directions that he has been termed the "creator" of analytical chemistry.

In France the cause of analytical chemistry was at that time furthered chiefly by Vauquelin, a pupil, and later on an assistant, of Fourcroy's. His researches extended to both mineral chemistry and to some of the so-called organic substances. His lectures and his laboratory instruction were largely attended and exercised undoubted influence on the generation of chemists next succeeding. Of his writings, the *Introduction to Chemical Analysis* should be mentioned ; this was published in 1799, and a German translation of the same was made. Like several of his co-laborers in analytical chemistry, Vauquelin had the good fortune to discover a new element, chromium. He also discovered and described the oxide of beryllium, the metal of which, beryllium, was isolated only thirty years later, by Wöhler.

The greatest improvements in analytical methods in those days were, however, wrought by a Swedish chemist, Jöns Jakob Berzelius, who had set for

himself as his goal the critical examination of numerous chemical compounds in order to learn their exact composition and to discover the laws which governed their formation. His work pointed the way for the accurate determination of atomic weights and practically established the doctrine of proportions.

Among the pupils of Berzelius, whose names are also deservedly eminent in the list of analytical chemists, there must be cited, Nils Nordenskjöld, Heinrich and Gustav Rose, Mitscherlich, C. G. Gmelin and Friedrich Wöhler. Heinrich Rose's *Ausführliches Handbuch der Analytischen Chemie* long ranked as a model of its kind.

Of English chemists who achieved marked success in this branch of chemistry, there might be named Edward Howard, who gave much attention to the analysis of meteorites; Smithson Tennant, who discovered osmium and iridium, and who, in 1796, was the first to make an experimental investigation of the chemical nature of the diamond, showing the same to be but a pure form of carbon; Dr. Henry, who devoted much skill to the analysis of gases, and

William Hyde Wollaston, whose work has been previously referred to.

One of the most distinguished analytical chemists of our own time was Carl Remigius Fresenius. An assistant of Justus von Liebig's, in Giessen, and later an assistant professor at that University, he established at Wiesbaden, in 1848, a laboratory which has since gained a world-wide reputation.

His manuals on Qualitative and Quantitative Analysis are to-day regarded as the standard works on these subjects, and his *Zeitschrift für Analytische Chemie*, founded in 1862, is still the leading journal of its kind.

Organic  
Analysis  
and Syn-  
thesis

Before the time of Robert Boyle, all substances were classified in accordance with their physical properties. Chloride of zinc, chloride of antimony and chloride of arsenic were designated respectively as *butyrum zinci*, *antimonii*, *arsenici*, simply because they all had about the consistency of butter; they were actually classed with this substance. Oil of vitriol, the sulphuric acid of to-day, was placed into the same group with the fatty oils, while sugar was counted in with the salts because it was a colorless substance soluble in water.



In a text-book on chemistry, entitled *Cours de Chymie*, first published in 1675, the author, Nicolas Lemery, classified substances according to their source or origin; he thus distinguished three classes of bodies,—mineral, vegetable and animal. Lemery's book was at the time regarded as the standard work on chemistry, and as it experienced translation into many tongues, his system of classification met with general acceptance.

It was only towards the close of the last century that the products of the vegetable and animal kingdoms, so called, received any appreciable attention from chemists. Scheele and Bergman studied some of the organic acids and worked out methods for their analysis, while the subject of animal chemistry received consideration at the hands of Rouelle.

Lavoisier determined the constituents of vegetable compounds to be, usually, oxygen, hydrogen and carbon; animal substances, he found, contained in addition nitrogen, and sometimes phosphorus. In Lavoisier's eyes, oxygen was, so to speak, the centre of the chemical world; in most instances he sought to determine whether a body was in combination with oxygen, or, if not, whether its combina-



tion with oxygen could be effected. To a body thus in combination or capable of combining with oxygen he applied the term "radical"; a radical might be either a simple or a compound substance. This was, as previously stated, the foundation of the theory of compound radicals later advanced by Berzelius.

Sharp distinction between animal and vegetable chemistry was gradually allowed to fall into disuse when it was ascertained that there were some substances which occurred in both the animal and the vegetable world; then the products of both of these kingdoms were grouped together as *organic* substances, and were classed apart from bodies of a mineral, or, as it was termed, an *inorganic* origin.

Berzelius, after a most thorough research, reached the conclusion that the so-called organic bodies were in their composition also subject to the laws of constant and multiple proportions.

The boundary line between organic and inorganic substances was, however, not clearly defined. Gmelin cited, as a distinguishing characteristic, that organic bodies could not be formed artificially from their components, while synthesis,

which means a building up from their constituents, was possible in the case of inorganic compounds. But other views were also held, the chemists of that time being by no means agreed as to what constituted a proper definition of organic and of inorganic substances.

The discovery by Friedrich Wöhler, in 1828, that amonium cyanate, a mineral substance, could be transformed into urea, distinctively an animal product, marks the first drawing aside of the veil wherewith Dame Nature was believed to screen the mysteries of the living world.

At that time, the belief was commonly held that all compounds found in the animal and in the vegetable kingdom owed their existence to the influence of a mysterious vital force. The elements under the domain of life were supposed to be governed by laws of their own, and, while it was known that substances found in plants and animals could be caused to undergo changes and transformations, it was not believed to be possible that they could be artificially made from their component elements.

It was a long time ere the full and general bearing of Wöhler's discovery came to be thoroughly appreciated,

ere the belief in a vital force was abandoned to be replaced by a well-founded faith in the possibility of the synthesis of all organic compounds.

**Spectrum  
Analysis**

When, in analytical determinations, the means and methods of chemistry alone are not sufficient to secure the required degree of accuracy in the results sought for, the aid of a sister-science, generally of physics, is invoked.

An illustration in point is spectrum analysis, a field of investigation opened up through the use of an instrument called a spectroscope. By the aid of this device the chemist is enabled to learn the composition of many substances under the sun, in fact, even of the sun, by examining the light which comes to us from that body.

When a beam of sunlight is allowed to pass through a prism, the various rays of which the white light consists are unequally refracted, and, in consequence, are separated from one another in emerging from the prism. These vari-colored rays, exhibiting all the colors of the rainbow, are designated as the spectrum.

Three kinds of spectra are distinguished. The solar spectrum and the spectra given out by the stars consist of

colored bands traversed in certain parts by dark lines. Solids heated to incandescence, but emitting no vapors—platinum, for instance—give rise to continuous spectra, that is, to bands of color unbroken by dark lines. Vapors of volatile substances, especially vapors of the metals, cause so-called bright line spectra. As each metal has a spectrum peculiar to itself and which is perfectly characteristic with respect to the color, the position and the number of the lines it exhibits, the value of spectrum analysis for the purposes of chemical research will be readily appreciated.

Credit for applying the principles of spectrum analysis to problems of chemistry belongs to two German chemists, Bunsen and Kirchhoff. By its aid they discovered the elements caesium and rubidium ; gallium, thallium and indium were likewise discovered by means of the spectroscope, by other analysts.

In an address, entitled "The Chemistry of the Stars," recently delivered by J. Norman Lockyer, this distinguished scientist, after recounting recent information gained in stellar chemistry by means of the spectroscope, referred to the process of celestial evolution, and

suggested the probability that all cosmical bodies were evolved from meteorites. Surely a great and important generalization to found on evidence supplied by a method of nature-study which had its modest beginning only at the beginning of this century.

**Electro-  
Chem-  
istry**

One of the most important advances made in chemistry in the first decade of the nineteenth century, was the securing of two new elements, potassium and sodium, from their compounds, potash and soda respectively, by the aid of electrical power. This was accomplished in 1807 by Sir Humphry Davy, who used electric currents in these investigations.

Water had been decomposed electrolytically, seven years earlier, by Nicholson and Carlisle. Berzelius had tried the action of electricity on salt solutions, ammonia and other compounds, and Sir Humphry Davy commenced his work in this direction by a very careful study of the electrolytic decomposition of water.

Davy's observations laid the foundation of the electro-chemical theory, which, later on, was materially enlarged and elaborated by Berzelius. A number of new elements were discovered by dissociating chemical compounds by the aid

of the electric current. Besides potassium and sodium, calcium, barium, strontium, chlorine and iodine were thus added to the list of chemical elements. Among the French, these researches excited great interest, and Gay-Lussac and Thénard paid great attention to the preparation of the alkalis named, potassium and sodium, by electro-chemical methods, in addition to seeking to obtain these metals by other processes of manufacture.

Employment of the electric current for the separation of metals was advocated in 1865 by Lückow, and its introduction into analytical chemistry was due chiefly to this investigator and to Gibbs. Within the past decade, thanks to the efforts of Wilhelm Ostwald, Alexander Classen, Robert Lüpke, Edgar F. Smith and others, the methods of electro-chemistry have reached so advanced a stage, that regular systems of qualitative analysis by electric currents have been devised, and by these means and methods satisfactory determinations of many bodies can now be made.

A study of the influence of electricity on certain of the so-called organic substances is one of the latest phases upon

which electro-chemical investigation has entered.

**Physical  
Chem-  
istry**

Fraught with potent powers for the good, for the advancement of all chemical knowledge, are the teachings of physical chemistry.

Physical chemistry is the name by which there is designated that border-land of science lying between chemistry and physics. Its scope may perhaps best be defined by stating that it aims at the solving of chemical problems by physical means and also at the solving of problems in physics by invoking the aid of chemical methods.

A pioneer in this field was Oliver Wolcott Gibbs, a distinguished American chemist. In Germany, Wilhelm Ostwald, W. Nernst and J. H. Van't Hoff are among the leaders of the movement along these lines.

Other chemists whose names are identified with advanced work in pure chemistry are: Ira Remsen, J. P. Cooke, William Crookes, Arrhenius, Raoult, Wurtz, Le Bel, Guldberg and Waage. In Germany, the *Zeitschrift für Physikalische Chemie*, edited by Ostwald and Nernst; in America, *The Journal of Physical Chemistry*, edited by Bancroft



and Trevor, are the representative organs of this especial branch of the science.

We may here not transgress into this fascinating domain nor enter into a discussion of its interesting possibilities. Exploration of it has, so to say, hardly commenced, but even so, it has already yielded great treasures to science and is full of promise for the future.

The origin of metallurgical knowledge dates back to prehistoric times, different nations ascribing the creation of the art to their gods and heroes.

Gold and silver were probably the earliest known of the metals ; this is easily accounted for through their occurring in the native state, that is to say, in the elemental condition, so that they could be employed as found, without first having to be obtained from their ores. The oldest manufactured object of gold to which a date can be assigned is a bead, shaped somewhat like a crescent, which was found by Monsieur de Morgan in a royal tomb at Nagada, in Egypt ; the probable date of erection of that structure is about 4400 B.C.

Nearly all ancient articles of gold which have been analyzed have been found to contain some silver. This

natural alloy of gold and silver—for such it may be considered—was termed electrum ; it occurred in considerable quantity in Asia Minor. The earliest coins, the introduction of which Herodotus ascribes to the Lydians, were made of electrum. They resembled oval bullets in shape and were stamped on one side only. Their use dates back about seven centuries before the beginning of our chronology.

Pure silver in ancient times seems to have been used principally for the making of jewelry and of other ornaments. Reference to a ring of silver is to be found in a translation of *The Book of the Dead* by Wallis Budge ; this reference would seem to make the existence of silver rings date back to at least 3600 B.C.

Copper and its alloy, bronze, have been known from the very earliest of times ; articles made therefrom have, it is claimed, been found in deposits dating back to the age of stone. In the tomb at Nagada, previously referred to, there was also found a button, which, according to the analysis of Berthelot, consisted almost wholly of pure copper.

Copper articles of somewhat later dates are frequently found to contain arsenic ;

this was probably added to harden the copper. Tin alloyed with copper constitutes bronze ; objects made of this material were used in Egypt evidently in very early times.

The use of iron was known to the Egyptians long before this metal passed into the hands of the Greeks and Romans. The time when it was first used in Egypt is a matter of dispute. Lepsius holds that it was there employed fully five thousand years ago.

Strange as it may seem, in spite of its wide usefulness this metal was regarded by the Egyptians as "the impure metal," and its handling was held to be a sin. This ancient superstition passed, together with the metal, into the keeping of other nations and may to this day be traced in various countries far distant from each other ; it is, for instance, encountered in Africa, in China and in Scotland.

Several metallurgical operations were known to the Romans and the Greeks, but hardly any information has come down to us concerning the chemical processes employed in those times. Diodorus, in the second century before our era, described a process of cupelling gold for removing impurities from that metal.

The process of heating cinnabar with iron, in order to obtain metallic mercury from this compound of mercury and sulphur, was also then known.

Mining was actively pursued in various countries, notably in Spain, France and Germany, as early as the eleventh century ; the mercury deposits in Idria were discovered towards the end of the fifteenth century, and the tin mines of England have been worked since very early times.

During the age of medical chemistry Agricola carefully described the chemical operations involved in metallurgical processes. By-products were noticed and secured, and about the middle of the sixteenth century the discovery was made, in Germany, that cobalt oxide imparts a blue color to glass.

The eighteenth century brought Bergman's investigation on the differences between cast-iron, wrought-iron and steel ; Réaumur's teaching of a practical process for the making of steel from iron, and Duhamel's study of the making of brass. About that time several treatises on metallurgy were published, among them Schlueter's extensive work, which appeared in 1738.

In the nineteenth century the process of making steel, devised by Sir Henry Bessemer, in 1856, has been perhaps the most important and, in its effects, the most far-reaching of all of the numerous advances made in metallurgical operations. The removal of phosphorus from iron, by the Thomas-Gilchrist process, and the utilization of the resulting slag as a valuable fertilizer, mark other achievements of this century in this particular field, which are of great importance and value.

Considerable attention has also been given within recent decades to the making of various combinations of metals, alloys, as they are termed. New varieties of brass and of bronze have been manufactured ; aluminium, which owes its present prominent position in the world of metals in a great measure to its cheap production by electro-chemical processes, forms the basis of a number of exceedingly valuable alloys, bronzes and others.

Various methods have also been found for securing the intimate combination of iron and steel with varying amounts of carbon, nickel and other elements. This results in the securing of great strength and power of resistance for the finished

products. In this respect, indeed, the great and enduring struggle for supremacy going on, the civilized world over, between heavy armorplate for purposes of defense and heavy projectiles for purposes of attack, may well be looked upon as an episode in the evolution of this particular branch of metallurgical chemistry.

Quite recently the United States Navy Department has received an extensive report concerning a very important experiment which extended over a period of four years, and which was made to determine the feasibility of attaching a covering of copper directly to the steel or iron hulls of vessels.

The process employed is practically one of electro-plating, the copper being, as it were, fused directly into the plates of iron or steel. The coating of copper thus applied has a thickness of about one thirty-second of an inch.

The results obtained in this Government trial have proved eminently satisfactory in every respect. The process is less costly than the process of copper-sheathing as ordinarily employed; the hull of the vessel experimented upon was found to be free from all barnacles, even

after long continued service in southern waters, and last, but not least, it was established that no galvanic action had been set up between the iron and the copper, although such an occurrence might have been feared.

Taken all in all, the successful outcome of this crucial test seems to mark a new departure along lines where the need of improvement had long been felt and sought, and this new process will probably prove to be of the greatest value to the shipping interests of the world.

Incidental reference should here be made to the various metallic pigments which play quite a rôle in the arts and industries. Among such colors, we have white lead, paris green, zinc white and iron ochre. Salts of iron, chromium, aluminium, tin and potassium are also largely used in the dyeing and the printing of textile fabrics.

The marvelous advances made by electricity have caused its influence to be strongly felt also in matters chemical. The winning of metals by electrical processes has previously been mentioned, and the practical applications of electro-metallurgy in the arts and in manufacture are numerous.



Electro-plating, the process of covering surfaces with metallic deposits thrown down from solutions of their salts by electrical currents, has made wonderful strides since the first inception of the idea by de la Rive, in 1836.

The production of whole series of chemical compounds, for instance, the silicides and the carbides, is also effected through the aid of powerful electric currents, which are caused to generate intense heat. Thus, carborundum, which is a carbide of silicon, is formed in the manner indicated, from a mixture of coal, sand and salt ; it has found considerable application in the arts, on account of its very great hardness, it replaces emery for many purposes and it is also used in the making of steel.

Calcium carbide, which is made by fusing coke and lime in an electric furnace, yields, when brought into contact with water, that brilliant illuminant, acetylene, which of late has entered into active competition with the illuminating gas now in common use.

**Mineral-  
ogical  
Chem-  
istry** The analytical work of Bergman, Vauquelin and Klaproth forms the true foundation of mineralogical chemistry, although sundry scattered observations

on the nature of minerals were made even in the seventeenth century.

It was Häuy who called attention to the importance of the crystalline structure of minerals, and in his system of classification he paid due regard no less to their physical than to their chemical properties.

In 1824, Berzelius announced his classification of minerals. This was based principally upon his own numerous analyses and soon displaced all other systems.

At one time considerable importance was attached to the theory of isomorphism, advanced by Eilhard Mitscherlich. This theory held that identity of crystalline form was dependent only upon the number and the arrangement of the atoms in a molecule and was in no wise influenced by the chemical nature of these atoms. According to Mitscherlich's teachings, an equal number of atoms united in the same manner would always give rise to one and the same crystalline form.

Among those who have been or are active workers in mineralogical chemistry, there should be cited the names of James D. Dana, whose *Text-book of*

*Mineralogy* is a standard work, and C. Rammelsberg, of Berlin, the author of the *Handbuch der Mineralchemie*, who in his day also contributed largely to the advancement of this branch of chemistry.

The first half of this century witnessed a few isolated attempts at the artificial formation of minerals, for instance, Gustav Rose's work on calc-spar and arragonite. But synthetic mineralogy, the producing of minerals in the laboratory while seeking to imitate Nature's conditions, dates virtually from the year 1851, when systematic attempts in this direction were first planned and made.

The methods employed embraced work with solutions as well as with fusions carried out at high temperatures; the results have proven of great value to geology, by making possible the testing of many geological hypotheses and by leading to the advancing of new theories.

Geo-  
logical  
Chem-  
istry

Among the most eminent German workers in chemical geology were Bunsen, who carefully studied the geysers of Iceland, and G. Bischof, who published a valuable treatise on the subject, the *Lehrbuch der Chemischen Geologie*.

Of American geologists who have attained to eminence in this field of

work, there should be named Thomas Sterry Hunt, who was long active in the geological survey of Canada and whose work on questions of chemical mineralogy is highly esteemed, and James Furman Kemp, whose standard publications on geology also contain various important contributions on topics of this character.

The French have been most active in the synthetic work along these lines—to mention only St. Claire Deville, Troost, Sarasin and Moissan. Moissan, in 1892, succeeded in making minute diamonds by exposing sugar-carbon and iron filings, while under great pressure, to a temperature of over five thousand degrees and then suddenly cooling the mass.

A sudden chilling, under enormous pressure, seems to be a necessary condition for the synthesis of diamonds; geologists have not yet succeeded in determining the mother-rock of this gem. An hypothesis recently advanced would assign to all diamonds an extra-terrestrial origin, holding that they are brought to this world by meteorites. Three separate finds of diamonds in meteorites have been made. One of these mes-

sengers from space fell in Chile, another in Siberia and the third in Arizona, U. S. America.

While there is not, as yet, sufficient evidence at hand to establish the above-mentioned hypothesis on anything like a probable basis, yet it remains an interesting fact that Moissan succeeded in obtaining diamonds synthetically, under conditions analogous to those to which meteorites that reach this earth are supposed to be subjected at one period of their existence.

#### Phyto- Chem- istry

The beginnings of phyto-chemistry, the chemistry of plant-life, can be traced back to investigations made at the close of the eighteenth century.

Priestley, Senebier and others were familiar with the fact that green plants under the influence of sunlight will remove carbonic acid gas from the atmosphere and decompose it. They were also aware of the fact that ammonia salts are of value in stimulating the growth of plants.

Although the problems of plant-life, the mode and manner of plant-nourishment and growth, had engaged the labors of many trained observers for many years, yet, even during the first

three decades of this century the belief was almost universal that plants, like animals, derived their nourishment directly from organic matter.

It was Justus von Liebig who demonstrated the falsity of these views and who entirely disproved the humus-doctrine, as the theory held at that time was called. It was in 1840, after exhaustive investigations on the weathering of rocks, on the formation of soils and on the effects of rain and the gases which rain holds in solution, that von Liebig published his classic work on the application of chemistry to agriculture and physiology.

In this he demonstrated that the food of plants is inorganic in its nature. The parts played by carbonic acid, by water, by ammonia and by various mineral salts were pointed out, and the fact was established that restitution must be made to the soil of such constituents as are removed therefrom by vegetable growth, if a given soil is to continue producing crops indefinitely.

When Nature is left to her own time and devices, she replenishes the needed store by the disintegration of the rocks. This is accomplished through the agency

of frost, by the solvent power of water containing carbonic acid, and, last but not least, through the silent but ever-active agency of the industrious earth-worms.

Our knowledge of the last named we owe chiefly to the illustrious naturalist, Charles Darwin. Earth-worms live in burrows, in the superficial layers of the ground. They can live anywhere in a layer of earth, provided only that the same retains a sufficient store of moisture, for dry air is fatal to them. They live principally in the mold, less than one foot below the surface, but in dry weather they sometimes go down to a depth of eight feet.

Their burrows end in small chambers, large enough to admit of the worms turning in them. These burrows are formed through the earth being swallowed by the worms for the sake of the decomposing vegetable matter which it contains and on which the worms feed ; leaves also form part of the diet of these little animals. When decaying, these leaves give rise to the formation of certain acids, but these acids are neutralized by some carbonate of calcium secreted by certain small glands the worms possess ;



these glands empty into the alimentary canal. Digestion of the vegetable matter is secured by the aid of a digestive fluid which resembles the pancreatic juice of the higher animals; it acts only when alkaline.

One part of the alimentary canal of these worms forms a hard, muscular organ, which is capable of grinding the food into fine particles. Small stones, swallowed with the earth, act as mill-stones, and the earth therefore is continually, as it were, passing through a mill, and is thus being constantly ground into a fine mold.

After the earth has been thus treated by the earth-worms it is voided as castings. The mold in a field passes through the bodies of these worms several times a day, and the earth particles are therefore brought to the surface again and again to be acted on by the rain and carbonic acid. Furthermore, through the collapsing of old burrows the mold is kept constantly in slow movement, and its particles are thus continually ground against one another. It has been calculated that in one acre of land, suited to their needs, more than fifty thousand earth-worms can exist; the importance

of their influence may therefore be readily inferred.

However, when the conditions are such that land cannot be allowed to lie fallow for the length of time needed by nature to carry out her purpose, chemistry comes to the rescue, and, accomplishing in a few hours the task that without her aid would have required years, gives to the cultivator of the soil fertilizers, the needed food for his crops, in a form to be readily assimilated by the plants.

Chemistry has taught man to know aright the requirements of Mother Earth, the conditions which must be fulfilled to ensure bountiful crops. No longer need virgins be sacrificed to the Genius of Maize, as was done by some tribes of American Indians, in order to plead for a generous yield of the life-sustaining cereal.

Notwithstanding the fact that the questions how plants feed and how plants grow have claimed the interest and the earnest work of many distinguished investigators these many years, we have as yet no positive knowledge as to the exact manner in which the inorganic constituents, water and carbonic acid gas, are by the plants transformed into

organic products, such as starch, the sugars and cellulose. These substances, produced by the plants are the food of animals; these in turn, when they die, again furnish the chemical compounds necessary for the life and the growth of plants, thus establishing and completing an endless cycle.

Another tempting problem which has received much attention at the hands of phyto-chemists, but which has as yet not found its full solution, is the chemistry of the color changes which foliage experiences in the fall.

It is, of course, well known that plants, their leaves and their flowers owe their colors primarily to the magic touch of light. Thus, a leaf in its period of vitality absorbs all tints of light except the green; this it reflects, and hence the leaf shows a green color. But as the vitality of the leaf declines, changes—chemical changes—occur in at least one of its constituents, the chlorophyll, and then the sunlight falling upon the leaf is differently affected. Various hues are reflected as the chemical changes progress. The leaf, erstwhile green, assumes in turn tints of yellow, orange, red—a play of colors which serves to render our

woodlands so beautiful in autumn. It has been stated that the sequence in which the colors of the turning leaves appear is the same as the order in which the colors of the spectrum range; following the green come yellow, orange and red—evidently favorite tints on the palette of Nature.

**Techno-  
logical  
Chem-  
istry**

The achievements of chemistry in the arts and industries are so vast and so varied, that the mere attempt to enumerate them all would prove a task scarcely less formidable than the counting of the denizens of starland, some twenty thousand of which are believed to exist for every one that is visible to the unaided eye.

Pure chemistry and applied chemistry are ever inter-active. The latter profits by the advances made by the former, while pure chemistry is in turn benefited by the new possibilities and opportunities created and offered by the industries. While the evolution of the science and its ministrations have gone hand in hand, yet it is unquestioned that a practical, an empirical knowledge was had of many processes, chemical in their nature, long before there was any true conception of their character.

Of the older nations the Egyptians were probably most favored with knowledge of this description. They were familiar with certain metallurgical processes ; for instance, the working of iron and its tempering ; gold was by them fashioned into ornaments, the rich mines of Nubia furnishing them with most of this precious metal.

To them was known the art of pottery, the glazing of earthenware and the use of colored enamels. The manufacture of glass was also practiced in Egypt and is supposed to have originated through an accidental fusion of sand and soda, in the fluxing of gold. The making of glass vessels was carried on extensively in Thebes and even the making of artificial gems of glass was known in Egypt in its early days.

Dyeing fabrics and the use of mordants for the purposes of fixing certain colors on cloth was known to both the Egyptians and Phoenicians. The former also used chemical substances in their practice of the healing art and in the embalming of their dead.

The tanning of leather by oil and later by means of bark was practiced by some nations of old. The use of soaps—com-

pounds of fats and an alkali—was known in Germany and in Gaul, even in the times of Pliny ; the purifying of clothes by the burning of sulphur is also mentioned by this author.

Acetic acid, in the form of vinegar, was another chemical agent with the properties of which antiquity was acquainted. This is apparent from the use Cleopatra is said to have put it to as a solvent for some valuable pearls ; this solution she drank, the act being prompted by her desire to gain the distinction of having partaken of the most costly banquet that could be furnished.

Technological chemistry finds a wide field of usefulness in the treatment of many substances which occur in nature and which possess a certain value even in their crude, natural condition, but which can be much improved in quality and in value by appropriate processes.

Thus it is probable that the sugarcane, as such, served as food before any attempt was made to express its juice and to boil the same into syrup. It is likely that this practice originated in India.

The first making of solid sugar must be placed somewhere between the fourth

and the seventh century of our era, probably nearer to the latter than the former date. The earliest description given of its manufacture is by a Chinese traveler, Hiuen-Thsang, who saw the process carried on in India and who assigned to the solid sugar the name *Chimi*—a Chinese term signifying “stone-honey.”

Even a few centuries ago sugar was regarded as a luxury. In 1372 sugar was valued in France at five dollars a pound; at the close of the sixteenth century its price in that country was still almost a dollar per pound and similar values obtained elsewhere.

In view of such figures it does not seem difficult to place credence in the tale of the thrifty housewives of New Amsterdam, who, so tradition affirms, were wont to provide but one lump of sugar, fastened by a string to the rafters of the dining-room, for the common use and enjoyment of the household. Surely an impressive object-lesson on the difficulty of attaining to the sweets of life!

But now, thanks in great measure to the advance of technological chemistry, sugar has become a cheap food-staple of many countries, the total world production of this article—“crystallized



sunshine'' as it has so aptly been termed—now approximating to seven millions of tons per annum, and representing a value of many millions of dollars.

Coal tar is the basis of many brilliant colors and of many valuable medicinal preparations. From it there has also been obtained a sweetening agent, saccharin, which of late years, under various names, has been offered as a substitute for sugar.

Saccharin, or, to give it its proper chemical appellation, anhydro-ortho-sulphamid-benzoic-acid, is a compound of the elements carbon, hydrogen, oxygen, sulphur and nitrogen ; it was discovered in 1879. It is a white, crystalline substance, soluble, though not readily so, in cold water and is characterized by an intensely sweet taste ; its sweetening power is estimated to be, for equal weights, from three hundred to five hundred times that of pure sugar.

While saccharin and other similar substances may have some value as medicinal agents, their attempted substitution for sugar in the preparation of food and drink is decidedly reprehensible. Not only is sugar a true food, which saccharin is not, for taken into the system it is

eliminated unchanged, but there is abundant evidence on record establishing the fact that saccharin interferes with the proper exercise of the digestive function. In some instances even decidedly injurious effects on men and on animals have followed the use of this preparation.

Many attempts have been made to produce food-substances synthetically. While it is claimed that the syntheses of sugar and albumen have been accomplished, yet we are to-day as far as ever from having achieved any practical results along these lines.

In some instances, however, valuable results have been obtained in modifying certain natural products in such a manner as to fit them for consumption as food-stuffs. An illustration in point is the manufacture of oleomargarine, butterine or artificial butter, as it is called, which dates back to the experiments of Mège-Mouries, in 1870.

In a tank heated with steam he rendered carefully washed beef-suet with some water, a little potassium carbonate and some pepsin. After digestion of the mixture for the proper length of time and after the melted fats had risen to

the surface, some salt was added and the fat was removed. It was allowed to cool, to permit of the crystallizing out of some of its constituents, and the fluid oil remaining, the oleopalmitin, was squeezed out by presses. To the oil thus obtained some milk or cream and a little butter-color were added, the mixture was well churned and salted and was then ready for the market.

Leaf-lard is now largely used as the crude material in this process. In cold weather a little pure cottonseed oil is added to it in order to give an improved texture to the finished product. This industry has attained to considerable importance.

Endeavors have also been made to furnish the essence of foods in a compact form. For it is possible to put much food into a condensed form in which it will keep properly for a considerable length of time. Food tablets have been prepared of soup, of beef, of milk and of eggs, forming as it were, the very essence of nutriment.

But very grave doubts exist whether food in such a form can and will be properly assimilated by the animal system; in fact, some experiments made a year

or two ago by some United States troops in Colorado, with the so-called emergency ration, returned a very decisive negative in answer to the question.

In this connection reference may not be amiss to the interesting fact, that of late the preparation of carbonated liquids has been made very convenient through the introduction of small iron capsules charged with liquefied carbonic acid ; the capsules contain each about two grammes of the liquefied gas, a charge amply sufficient for the conversion of at least a quart of water, or other liquid, into a sparkling, refreshing beverage.

However, it would lead too far afield, even should one only attempt to indicate all the many chemical processes to which so great a number of the necessities and the comforts of our daily life are owing.

As furnishing a basis for many of these industries, there would have to be considered the manufacture of the mineral acids—hydrochloric, sulphuric and nitric; also the preparation of sodium carbonate and of other alkaline products.

The manufacture of textile fabrics of various materials—silk, wool, cotton, linen—would have to claim our attention. So

would the preparation of many colors and dyestuffs derived from animal, vegetable and mineral sources ; the art of pottery and ceramics ; the manufacture of paper, of ink, of matches ; the compounding of gun-powder and of smokeless powders, of nitro-glycerine and of other high explosives, with their powerful mission in peace and in war.

Besides, the making of sugar, the preparation of starch, of flour and glucose, the manufacture of alcoholic beverages of various kinds, the preservation of certain foods—one and all might be studied and called upon to bear witness to the importance of chemistry in its applications.

But, as it is not feasible to discuss all these in detail, interesting as it might be, there shall here be chosen in illustration but a few instances where the creative power of chemical science stands clearly revealed.

The preparation of artificial silk from cellulose is an instance in kind. Cellulose is the fundamental constituent of plant structure ; it forms a material part of the solid matter of every plant. In its chemical composition it is allied to starch, being, like starch, a compound of carbon,

of hydrogen and oxygen and having the same percentage composition as starch.

Cellulose is insoluble in water and in alcohol, it is tasteless and is not a nutrient. In the process here to be considered, the cellulose is brought into solution by treatment with chloride of zinc, and this solution is then forced in fine jets into a fluid like alcohol or acetone. This causes the precipitation of the cellulose in the form of fine continuous threads ; the reagents are dissolved and washed out, leaving only the desired product. The threads so obtained can be colored at will ; they can also be made waterproof and can of course be woven into fabrics of any desired shape and size. The finished article resembles silk so closely that even connoisseurs of the silkworm's product cannot always distinguish between the latter and its *fin-de-siècle* rival.

In this case it is a substance of animal origin which is skilfully imitated by chemical processes ; in the manufacture of artificial India rubber we have an instance of the substitution, after the proper treatment, of one vegetable product for another.

An English chemist, W. A. Tilden,

discovered that a peculiar liquid substance, isoprene, which had previously been obtained by the destructive distillation of India rubber, could be obtained by the influence of heat upon oil of turpentine, rape-seed, linseed and various other vegetable oils.

Isoprene is a compound of carbon and hydrogen ; it boils at a low temperature, about 40° Fahrenheit, and is converted, by treatment with strong mineral acids, hydrochloric acid, for instance, into a solid which is tough and elastic and which, also in other respects closely resembles India rubber. Many attempts have been made to provide synthetic substitutes for both gutta percha and India rubber ; the process here referred to for obtaining the latter certainly seems a promising one, if only it can be properly controlled on a manufacturing scale.

Many essential oils and other organic substances have been synthetically prepared. Among them benzaldehyde, the principal constituent of oil of bitter almonds, oil of cinnamon, cumarin—to which the Tonka bean owes its delicate aroma—and vanillin, the odorous principle of the vanilla-bean. This vanillin is made from coniferin, a substance which



occurs in spruces, in firs and in larches.

Even the flower's subtle charm, its perfume, needs no longer be extracted from the blossoms; for the odors of the heliotrope, the violet, the lilac and geranium, these and many more, can now be made in the laboratory and are as fragrant as though they owed their existence to the favored children of the dew and the sunshine.

Possibly one of the most striking achievements of technological chemistry is presented by the wonderful array of beautiful and brilliant colors which the chemist's art has called forth from coal-tar and from other apparently most unpromising sources. The great and extensive coal-tar color industry is built, in great part, upon the exhaustive studies of the famous German chemist, August Wilhelm von Hofmann, a man in whom there were combined to a rare degree the essential qualifications which mark the scientific investigator, the teacher and the scholar.

The aniline colors now number several hundreds and have almost wholly replaced the coloring matters formerly used — indigo, madder-root, cochineal, safflower and the yellow dye-woods.

Perkin, in 1856, made mauve from

aniline, one of the constituents of coal-tar oil. This was the first aniline dye to be prepared on a large scale.

A synthesis in organic chemistry which has produced far-reaching results in several directions, was the artificial preparation of alizarin by Gräbe and Liebermann. Alizarin is one of the coloring matters which occur in the madder-root. Its name was bestowed upon it by its discoverers, Colin and Robiquet, in 1826, the term being taken from the oriental appellation of madder, *alizari*.

The root of this plant has been used in Egypt and in India, since time immemorial, for the dyeing of cloth; wrappings found on mummies proved to have been colored by this substance. The culture of the madder plant was also practised extensively in Holland, in France and in Alsace, and about forty years ago the total annual production of madder was not far from five hundred thousand tons.

Gräbe and Liebermann found, as before stated, that alizarin could be artificially prepared; they obtained it, by a series of ingenious chemical reactions, from anthracene, a constituent of coal-tar. This was the first instance of the

synthetic production of a coloring principle which had formerly been obtained exclusively from a vegetable source.

One of the important results of this famous discovery was the turning over to agriculture for its purposes of vast tracts of land, which had up to that time been used for the cultivation of the madder-root. Gräbe and Liebermann's achievement also, incidentally, stimulated greatly the coal-tar industries and increased materially the manufacture of caustic soda and of sulphur trioxide.

Another instance, where synthetic chemistry produced a color that had for many centuries been obtained only from plants, we have in the artificial manufacture of indigo. This substance was used very long ago in India as well as in Egypt. In Europe, the woad, which also belongs to the plants that produce indigo, was for ages the chief source of supply of this dye; its use by the Gauls and by the ancient Britons is clearly established. In Germany its cultivation was practised as early as the sixth century and was carried on for many centuries thereafter. But gradually woad was supplanted by indigo and the use of this

substance as a blue pigment and as a dye became general.

The chemical composition of indigo received attention at the hands of several chemists. Fritzsche, in 1840, distilled indigo with caustic soda and secured a substance which he called aniline. This term is derived from the Sanscrit appellation *nila*, the indigo-plant, the word *nila* signifying dark-blue; as a matter of interest it may here be remarked that the name of the river Nile is said to be traceable to the same source.

Many chemists were concerned with the investigation of indigo. To name but a few, we have Laurent, Erdmann, Baeyer, Knop, Emmerling and Nencke. The last named succeeded, in 1875, in obtaining a small amount of artificial indigo by the action of ozonised air on indol. At present several methods of indigo-synthesis are known.

The synthetical preparation of ultramarine, a substance which replaced the costly *lapis lazuli* used in the painter's art, was effected after chemical analysis had revealed its quantitative composition. This will serve as an illustration of a mineral substance successfully produced in the laboratory and leading to

the establishing of an important manufacturing industry.

Any consideration of technological chemistry, however brief, would be incomplete without at least a passing reference to a recent achievement which is fraught with great possibilities for the future of many chemical processes — reference is made to the liquefaction of air on a commercial scale.

The possibility of the liquefaction of air, in quantity, was demonstrated in 1893 by James Dewar, of Edinburgh; Olszewski, of the University of Cracow, claims to have obtained this substance in small quantities even in 1884.

Dewar's method of procedure consisted in making use of liquefied carbonic acid or of ammonia, which, by its evaporation ensured the liquefaction of another gas, ethylene. This liquid was in turn employed to cool and to liquefy still other gases and liquid air was finally obtained as the end-result of a series of such operations.

It proved, however, a costly treasure, Dewar estimating the expense of obtaining a quart of liquid air at something more than two thousand dollars.

It remained for the practical ingenuity

of an American, Charles E. Tripler, of New York, to devise a process by which liquid air can be obtained so readily and at a cost sufficiently low to make it available for many purposes and in any quantity desired.

Mr. Tripler's process is based on the principle that gases which have been subjected to great pressure absorb much heat on being again allowed to expand.

By means of a forty horse-power engine, provided with three pistons furnishing respectively sixty, three hundred and two thousand pounds of pressure to the square inch, air in liquid form is produced solely through the aid of ordinary air which has been subjected to cooling and to these pressures.

The temperature of the air to be liquified is lowered to  $312^{\circ}$  below zero on Fahrenheit's scale. At this point it turns into a liquid that is practically colorless.

Air, as is well known, is essentially a mixture of oxygen and nitrogen—by volume, approximately one-fifth of the former and four-fifths of the latter gas. Nitrogen evaporates more rapidly from liquid air than oxygen and, in consequence, liquid air undergoes changes in

its composition on suffering evaporation ; it grows constantly richer in oxygen.

The chemical and physical properties of most bodies when brought into contact with liquid air are so wholly unlike the properties they exhibit at ordinary temperatures, that their study under these novel conditions seems like the opening up of a new realm to the explorer—an Arctic region, as it were, replete with wonders.

It must certainly be counted a great triumph of Science that she can thus impress into service the forces of Nature, and produce a cold so intense, that, by comparison with it, the lowest temperature ever recorded by intrepid explorers of the frozen North sinks into insignificance.

Liquid air when poured over ice boils at once and becomes transformed into vapor. As its temperature is more than 300 degrees below the temperature of ice, this result, startling as it seems, is inevitable. Thrown into a vessel of boiling water, liquid air instantly changes the boiling water into ice ; a jet of steam forced into liquid air immediately congeals into glittering crystals of frost.

Mercury, immersed in this novel re-



agent, becomes a solid, which is so hard, that, appropriately shaped, it can to all intents and purposes be used as a hammer as long as the magic spell of the frost-giant endures.

Most metals and many other substances turn brittle as glass when they are subjected to the action of liquid air. On account of its richness in oxygen, constantly increasing, it will be remembered, as its evaporation progresses, the presence of liquid air readily ensures combustion. Wires of iron and steel will, when ignited, burn freely in this liquid—itself so intensely cold.

Employment of liquid air as the motive power in engines of all kinds, application of its tremendous expansive and explosive force to the purposes of industry and of war, mark but a few of its many uses which the future will witness.

As soon as man shall have learned to perfectly control this new and powerful agent—advances in that direction have even now been made—it stands unquestioned that it will prove a potent factor for the good of mankind and the progress of civilization.

**Pharmaceutical**

The beginnings of pharmaceutical chemistry must be traced to the age of

iatro-chemistry, for at that period the preparation of medicines was the chief aim of chemistry. Chem-  
istry

Paracelsus may be regarded as one of the founders of pharmacy, inasmuch as he introduced into medicine the use of many chemical preparations employed even to this day. He prescribed as drugs, many metallic compounds ; among others salts of copper, of lead, of arsenic, of mercury and antimony. In the use of the last named he had, however, been preceded by Basil Valentine. Tincture of iron, dilute sulphuric acid, various essences and laudanum were also among the many curative agents employed by Paracelsus.

The reckless manner in which some of his followers used metallic preparations in their medical practice caused much trouble and discussion, and finally edicts against the use of such substances were issued. But even some of the adherents of the new school, that is to say, the school of Paracelsus, did not fail to perceive that there was not a little in the teachings of their master that might be discarded to advantage. Two notable men of this class were Croll and Van Mynsicht, the latter of whom intro-

duced tartar emetic into pharmaceutical practice.

Croll first made use of sulphate of potash and ere long the alkaline salts came to be of great importance in medicine. Among those employed were the chloride and the carbonate of potash; the sulphate of sodium—Glauber's salt, as it is now generally termed—was then designated as *sal mirabile* and was greatly prized by physicians on account of its valuable properties. The medicaments used gradually increased in number; nitrate of silver, various salts of acetic acid, salt of sorrel, acid juices of fruits, benzoic and succinic acids and many other substances were tried and added to the stores of pharmacy. Spirits of wine, the *aqua vitæ* of the alchemists, was turned to new account in the preparation of tinctures and of various essences. Valerius Cordus, a German physician, is said to have been the first to make ether from alcohol by means of sulphuric acid.

Within the past decades the skill of the pharmaceutical chemist has been directed to the discovery and the preparation of remedies which are not found in Nature, as well as to the synthetic

manufacture of many drugs which she does offer. The introduction of chloral hydrate, salicylic acid and antipyrin probably inaugurated this new departure ; to-day there are known long lists of hypnotics, narcotics and antipyretics that claim coal-tar or similar materials as their parent-substance. Certain glands and other organs of animals are also made to yield preparations which find valued application in the correction of some of " the ills that flesh is heir to."

One of the important lines of investigation lately entered upon in pharmaceutical chemistry is the attempt to trace the relation between the chemical composition of drugs and their physiological action. Some advances in this direction have even now been made ; what vast and far reaching consequences would follow the solution of this problem, the fulfillment of this day-dream of more than one eminent physician and chemist, can hardly be foretold. It would certainly mark a new era in the history of the practice of medicine.

During the second half of the last, and the earlier years of this century, the pharmaceutical profession was charged with the keeping of the best interests of

chemistry, through fostering the growth and development of many of its eminent disciples. In this connection one need but recall the names of Scheele, Vauquelin and Klaproth ; many others might easily be added to the list. Among the institutes of pharmacy of note in their time, the Trommsdorff Institute, established in 1795 at Erfurt, perhaps deserves special mention.

**Toxi-  
cology  
and  
Legal  
Chem-  
istry** It was a sad, but perhaps an unavoidable outcome of conditions that an increasing knowledge of the potent powers inherent in many drugs and chemical preparations should have led to occasional abuse and to their application for criminal purposes. A recital merely of crimes which have passed into history and which have been executed by the aid of poisons, would form a long and thrilling tale. But the advances made in analytical chemistry have fortunately made it possible for the science herself to be the Nemesis of those who misuse her gifts to further unlawful designs.

Toxicology, which embraces a knowledge of the poisons, their effects and their detection, has of late years met with increased attention and study, and

now it would prove rather an exceptional instance where the criminal use of a poison could not be detected and proven.

Chemical means and methods are also often employed in other instances to aid justice in tracing crime and in fastening the charge upon the guilty. The detection of forgeries in documents, the examination of blood and other stains, the determination of fraudulent and injurious adulterants in foods and in drugs, all come properly within the scope of chemical investigation and control.

The domain of physiological chemistry is broad in scope. Originally its aim was a study of the various tissues, the fluids and the solid components of the animal organism. Among the early investigators of these problems were Fourcroy, Vauquelin, Chevreul and Lavoisier; the latter giving expression to his belief that the processes of life were chemical in their nature.

Methods of analysis adapted to the requirements and calculated to overcome the peculiar difficulties of physiological chemistry were gradually evolved. Notable questions that were elucidated by their aid and through most painstaking research were, the composition of

Medical  
Chem-  
istry



bone-matter, the constitution of blood and the phenomenon of its coagulation, the composition of the gastric juice, of milk and of other secretions of the animal body, including the character and properties of the various constituents of urine.

Experimental study of the all-important question of animal nutrition was initiated and conducted by Justus von Liebig; his investigations and deductions regarding metabolism were a revelation to his contemporaries and aided materially in bringing about abandonment of the belief in the mysterious power of the so-called "vital force."

Von Liebig appreciated the different functions of the albumenoids, of protein and gluten, as tissue and muscle builders, and of the carbohydrates, sugar and starch, and of the fats as heat producers. Since his days the problems of nutrition and the composition of nutrients have never failed to claim the attention of eminent workers. Virchow, Pettenkofer, Ranke, Atwater, Wiley, are but a few of those who have enriched physiological chemistry in this particular direction by their labors.

When a fair knowledge concerning the chemical composition of the various con-



stituents of the animal economy had been gained, investigation was directed into new channels ; study was attempted of the relations which these various substances bear to each other, of the specific functions each has to perform and of the conditions under which these various substances are produced and destroyed.

Well-known among the men active in such researches are Preyer, Hoppe-Seyler, Virchow, C. Ludwig, Hammarsten and Chittenden.

The poisons which are formed in decaying animal matter, the so-called cadaver-alkaloids or ptomaines, were first investigated by Selmi. On account of the highly poisonous character which some of these possess, Brieger named them toxines.

When it had been ascertained that toxines of various natures are produced also in the progress of some of the diseases most fatal to human life, great skill and energy were brought to bear upon the seeking of antidotes for these poisons, and in this connection are to be recorded some of the most wonderful achievements of bacteriology and chemistry—the discoveries leading to the use of the so-called anti-toxines.

Here there will be recalled the discovery by Louis Pasteur of the specific agent by which that most terrible of diseases, hydrophobia, can be mastered ; the preparation of an anti-toxine with which the ravages of diphtheria have, in many instances, been successfully checked ; the preparation of Koch's serum by which the existence of tuberculosis in animals can be diagnosed and in consequence of which precautionary measures against the spread of this malady can be taken.

The first suggestion of producing unconsciousness, anæsthesia, through the inhalation of gases, is credited to Sir Humphry Davy. At least he was familiar to some extent with the properties of laughing-gas—nitrous oxide, as the chemists call it.

The anæsthetic property of ether—a substance discovered by Valerius Cordus, about 1530—was commented upon by Paracelsus in 1541. This important matter seems, however, to have been wholly lost sight of, forgotten, until the time when Faraday again called attention to it, three hundred years after ether was first known.

The inhalation of this substance as a

specific agent for relieving pain seems to have been first considered in October, 1846. At that time W. T. G. Morton, a dentist of Boston, applied to Dr. Warren, a surgeon of that city, to determine whether the vapor of ether could be used in allaying pain in surgical operations, as Morton had found it would do in dental practice.

Dr. Warren soon acted upon this suggestion and successfully used ether in an operation, in the Massachusetts General Hospital, Morton administering the reagent to the patient at the time. Shortly afterwards a Dr. C. T. Jackson, of Boston, in conversation with Warren claimed that it was he who had acquainted Morton with the use of this reagent for dental operations.

In 1847 an English physician, James Young Simpson, acting on the suggestion of a Mr. Waldie of Liverpool, introduced the use of chloroform as an anæsthetic.

The use of anæsthetics on the one hand, and the method of treating wounds antiseptically, introduced by the English surgeon, Sir Joseph Lister, will ever rank among the most brilliant achievements of medical chemistry.

The extensive studies of Pasteur on

fermentation have opened up the vast field of bacteriology with its wonders of the infinitely small. This topic is foreign to our present quest, but it is vividly called to mind in connection with the latest researches of E. Büchner, Tübingen, who would relegate the phenomena of alcoholic fermentation entirely to chemical action, claiming that this variety of fermentation is due, not directly to the growth of the yeast-plant, but to a kind of ferment obtainable therefrom.

Hygiene, the art of preserving health, has of course profited largely by the revelations of physiological chemistry. Having ascertained the character and the nutrient value of various classes and kinds of food, it was but a short step to seek to safeguard against their adulteration, which means, at the very least, a lowering of their normal and proper value. So important a matter has this come to be, that many larger communities maintain special officials for the sole purpose of watching and ensuring the purity of their food-supply.

Many diseases can be communicated through the agency of food and drink. Among the diseases which can be so

spread are tuberculosis, scarlet and typhoid fever and cholera. In former times the ravages of these scourges were almost unchecked until their full course had been run, but since the true cause and character of many of these contagious and infectious diseases have come to be understood—thanks in great part to the findings and teachings of bacteriology,—the aid of chemistry has been invoked to supply remedial and preventive agents. An account of the properties, the uses and the benefits conferred by antiseptics and disinfectants would form a chapter of no slight interest in a detailed history of medical chemistry.

As one of the most important and brilliant researches recently made in physiological chemistry there must be noted the endeavor of Professor Leopold Schenk, of Vienna, to influence the sex of human offspring by regulating the diet of the mother.

In his method insistence is placed upon the chemical nature of the food consumed and upon the complete combustion of this food in the system ; by means of chemical analysis a careful control is kept as to the regularity and the completeness with which this proceeds.

Schenk claims that under certain circumstances male progeny may be procured by aid of the influences which he has indicated ; creation at will of female offspring, he admits, is as yet beyond our ken. If his work bears the test of time and experience, a great advance in physiology will have been made, and in part through the aid of our science.

May we, dare we, hope that Chemistry the Beneficent, at whose shrine we all—knowingly or unknowingly—pay daily tribute and homage, will some time return answer to our pleading and reveal to us the long-sought secret of Life?



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